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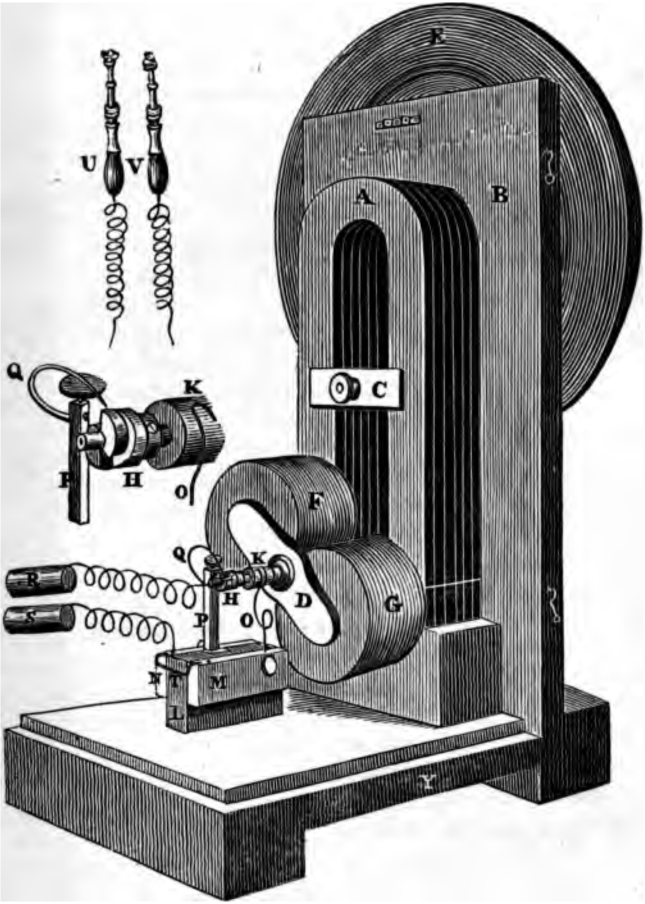

CLARKE'S MAGNETO-ELECTRICAL MACHINE.

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A COURSE

OF

EIGHT LECTURES;

ON

ELECTRICITY, GALVANISM, MAGNETISM, AND ELECTRO-MAGNETISM.

BY

HENRY M. NOAD,

MEMBER OF THE LONDON ELECTRICAL SOCIETY.

LONDON:
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THESE

LECTURES

ARE RESPECTFULLY INSCRIBED,

AS A SMALL TRIBUTE OF THANKS FOR HIS PAST

LABOURS IN THE SERVICE OF GALVANISM,

AND

AS A TESTIMONY OF THE SINCERE ESTEEM

OF

THE AUTHOR.

PREFACE.

The ceremonies of an Introduction are hardly required to present this little volume to the public. Its title sufficiently shows what it is, and what is to be expected from it. To say therefore, that it does not pretend to a scientific character, or to convey original information—that it does not look for support to scientific men, but to the taste of the public in general—is perhaps superfluous. Its object has been to show in as interesting, concise, and clear a manner as possible, the identity of the electricity derived from different sources. The establishment of this identity, was the object of the third series of Dr. Faraday's admirable "Experimental Researches," but at the time this was written, several links were wanting to render the connexion complete—these links are now supplied. Thus, chemical decomposition has been effected; physiological effects produced; and the spark elicited by thermo-electricity; and an electric eel is now exhibiting in London, from which the spark has been produced, in the presence of numerous witnesses. In many other instances also, the evidence, which, at the time when Dr. Faraday wrote, was barely sufficient to establish the question of identity in the mind of the philosopher, is now become so decided, as to admit of no doubt in the minds even of the most sceptical. I will merely adduce in proof, the splendid results which the recent investigations, in the department of magneto-electricity have afforded; an account of which is given in the eighth lecture.

It is presumed that in the present day, every enlightened person must be interested in the progress of science, though many, from the nature of their pursuits, may be prevented from giving much of their attention to it.—It is to such persons that these Lectures look for support; and if the general information which they convey, on the subject of one of the grandest and most mysterious of the sciences, has sufficient interest to beguile an idle hour, the object of the author will be attained.

SHAWFORD, DECEMBER, 1838.

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LECTURE I.

ON ELECTRICITY.

No branch of experimental philosophy is received by persons of all ages with greater pleasure than electricity; the reasons are obvious: it is the science susceptible of the most familiar demonstration, and its phenomena, from the striking and ocular manner in which they are presented, are calculated to arrest the attention, and become fixed on the mind more powerfully than those of any other science. To this may be added its connexion and identity with the most sublime and awful agencies of nature.—Its secret and hidden influence in promoting at one time the decomposition of bodies, and at another time their reformation. At one time, in its current form causing the elements of water to become separated and eliminated in the form of gases, and at another time, in its condensed form causing these same elements to re-unite and become again identified with water.—Now, in its current form, exhibiting the most wonderful and sometimes terrible effects on the muscles and limbs of dead animals, and now, in its condensed form, moving with a velocity that is beyond conception through the living body and communicating a shock through fifty or fifty thousand persons at the same instant.—Now exhibiting its mighty powers in the fearful thunder storm, and now working slowly and quietly in the development of beautiful crystals. With such varied subjects for contemplation and admiration, no wonder electricity should be so favourite a study.

I have said that electricity is the science susceptible of the most familiar demonstration. By this I must be understood to mean with reference to its *general laws;* for, as with other branches of natural philosophy, the investigation of its particular details, such as the ascertainment of the exact laws of attraction and repulsion, is a subject of difficulty, and requires the resources of mathematics. With this I have nothing to do on the present occasion; the design of the series of lectures I am now undertaking, being to give a popular history of the present state of the sciences on which I shall treat, and to show their connexion with each other.

Common electricity, which is to form the subject of the present and succeeding lecture, although occupying so prominent a place in modern science was quite unknown to the philosophers of olden times, and may be said to date its entrance into physics about the beginning of the eighteenth century. In the writings of Pliny and Theophrastus we meet with some remarks on the attractive power of amber and lyncurium stone (supposed to be the same with the modern tourmaline) for light substances, when rubbed, but no attempt to explain this property is made. In the year 1600 Dr. Gilbert published a work on magnetism, in which he mentioned several new facts attributable to electrical agency, and greatly multiplied the number of substances capable of acquiring electrical properties. This drew the attention of philosophers to the subject, and it was in 1720 that the true foundation of electricity, as a science, was laid by Mr. Stephen Gray. It was this experimentalist that introduced the distinction between electrics and non-electrics; conductors and non-conductors: his papers are to be found in the philosophical transactions between the years 1720 and 1736. Du Fay was the next contributor. From him it was learnt, 1st.—That conductors as well as non-conductors can be excited by friction, provided they are insulated; which precaution was neglected by Gray. 2nd.—Electrical bodies when excited, attract those not excited, give them electricity, and then repel them. 3rd.—There are two kinds of electricity: one produced when smooth glass is rubbed with woollen cloth, and hence called *vitreous;* and the other called forth by rubbing amber, sealing wax, or any resinous body with warm flannel, and hence called *resinous.* Bodies having the same kind of electricity repel each other, but attract those having a different kind. The reason why an excited body attracts light substances, is because it produces in them electricity different from that which they themselves possess; and hence they are drawn to the excited body in obedience to the general law.

It was in the year 1746, that those celebrated experiments which drew for many succeeding years the almost exclusive attention of men of science to the new subject, and which led the way to the introduction of the Leyden phial, were made by Messrs. Cuneus, Muschenbroeck, and Allamand. These gentlemen conceiving that an excited body might be made to retain its electricity much longer, if entirely surrounded by electrics, suspended from the ceiling a gun-barrel by silk strings, and bringing one end near a glass revolving globe, caused a wire attached to the other end to pass into a vessel of water held in the experimenter's hand. After a few revolutions of the globe, the gun-barrel was touched with the view of obtaining a spark. The consequence, to the unspeakable astonishment and alarm of the experimentalist, was an electric shock, which, although very slight compared even with such as are now frequently taken for amusement from the Leyden phial, yet, from its novelty and unexpected appearance was magnified into a most tremendous and painful concussion, so much so, that several persons who were prevailed upon to try it, were heard to declare that no consideration should induce them to repeat the experiment. Mr. Muschenbroeck in describing in a letter to Mr. Reaumur the effects of a shock taken from a thin glass bowl, says "I felt myself struck in my arms, shoulders and breast,—I lost my breath, and it was two days before I recovered from the effects of the blow and the terror;"—he adds that he would not take a second shock for the kingdom of France. Such was the alarm with which those early electricians were struck, by a sensation which thousands have since experienced in a much more powerful manner, without any inconvenience. It serves to show how cautious we should be in receiving the first accounts of extraordinary discoveries, where the imagination is likely to be affected.

Many attempts were made to explain the phenomenon of the electric shock, but it was reserved for the celebrated American philosopher Dr. Franklin, to do so in a satisfactory manner.

The publication of his "Experiments and Observations at Philadelphia," in 1754, forms a remarkable æra in the history of electricity. The opinions contained in this work are opposed to those of Dufay, but were nevertheless almost universally adopted.

Franklin supposes that only *one* electric fluid exists, and that all electrical phenomena are referable either to its accumulation in bodies, in quantities more than their natural share, or to its being withdrawn from them, so as to leave them *minus* their proper portion. Thus then, electrical accumulation exhibits the vitreous, and electrical deficiency the resinous electricities of Du Fay; and hence the terms positive and negative, for vitreous and resinous.

Besides this theory, we are indebted to Franklin for three important additions to the science :—1st. Dissipation, and the consequent impossibility of accumulating electricity in bodies furnished with points. This led to the employment of the thunder rod for protecting buildings from lightning. 2nd. The discovery of the identity of lightning and electricity, and the fact, that the former with thunder is occasioned by the accumulation of the latter. This he proved by drawing lightning from the clouds, and performing with it the same experiments, as with common electricity. And 3rd. The analysis of the Leyden phial. Of each of these in their turn.

In 1759 and 1771, Epinus and Mr. Cavendish exhibited Franklin's theory in the garb of mathematics; and in 1779, a most valuable work was published by Lord Mahon, in which he shows that the quantity of electricity in an electric atmosphere, that is, in the air surrounding an excited body to some unknown extent, *diminishes inversely as the square of the distance.* Hence the reason why an electric atmosphere cannot possess any sensible electric properties, at a considerable distance from the excited body. This investigation led to the discovery of the *returning stroke.*

Coulomb's discoveries stand next in order. They were published in 1785 and 1786. By means of his torsion electrical balance, *he* made three valuable additions, which, in fact, constitute the first principles of electrical theory. 1st. Electrical forces, viz.—attraction and repulsion, vary, *inversely as the square of their distances,* following, it will be observed, the same law as gravitation. 2nd. Insulated, excited bodies, gradually lose their electricity from two causes: one is owing to the surrounding atmosphere being never free from conducting particles, and the other from the fact that the best insulators are by no means impervious to electricity. Coulomb determined the effect of both these causes. 3rd. When electricity is accumulated in any body, the whole of it is deposited on the surface, and none penetrates to the interior. A thin hollow sphere may contain precisely as much electricity as a solid of the same size. Hence accumulation is not a consequence of attraction for mass of matter, but on the contrary, is solely due to its repulsive action.

For a long time it was supposed, that the electrical agent could be excited by friction only, and all the phenomena were classed under the general term electricity; subsequent investigation has shown that this is by no means the case, that it may be influenced and elicited by chemical action; by rapidly breaking and renewing the contact of the armature with the poles of a steel magnet; by electro-dynamic induction, that is by disturbing the natural latent electricity of a coil of copper wire, by allowing a current of voltaic electricity from a small pair of plates, to circulate through a second coil placed in a direction parallel to the first; by the action of heat on metals; and by the muscular action of certain fishes. Hence the subdivision of this science into the branches of common, voltaic, magneto, thermo, and animal. Our business at present is with the first of these only, namely common electricity, or electricity of tension.

It was mentioned above, that the earliest fact connected with electricity, that was observed, was the power which a body under its influence possesses of drawing towards itself light substances. A few simple experiments will serve to illustrate this, and to exemplify one of the first and leading principles. Suspend a small ball of dry elder pith, or a light downy feather perfectly clean and dry, by a long thread of white sewing silk; then take a glass tube and having warmed it at the fire, let it be excited by rubbing it gently with a piece of warm silk, then bring it near the suspended pith or feather, either will be immediately drawn towards it; remove the tube for a moment, and then bring it near a second time, the attractive force will be found to have given way to one of an opposite kind; the ball or feather will be steadily repelled, and for a short time it will be found impossible to make them touch the tube. By degrees, however, the small quantity of electricity which has been imparted to them by the glass, will become dissipated, and they will be attracted as before, and again repulsed. The same phenomena will occur over and over again, till the whole of the electricity has been withdrawn from the excited tube.

Now, let a stick of sealing-wax be rubbed with flannel, and brought near the suspended bodies, and they will be alternately attracted and repelled, *apparently* in the same manner, as when the glass was used; or, rub a sheet of writing paper with Indian rubber, then advance it with its rubbed side to the feather and the same will result; but, that the property which has been communicated to the wax by friction is *distinct* from that communicated to the glass by the same means, may be easily rendered evident, by advancing the wax to the pith ball or feather after they have been made *repulsive* of the glass tube, instead of further repulsion, instant attraction will be observed; and if the ball or feather be suspended between the excited glass and the excited wax it will vibrate from one to the other, being alternately attracted and repelled. From these trifling experiments we learn that there is a difference in the electricities of the glass and the sealing-wax, for one attracts a light body which the other has repelled. So we may either suppose with Du Fay that there resides a peculiar electricity in each, or with Franklin, that the electricity is the same in both, but in different states, that is, in the excited glass there is a redundancy, but in the excited wax a deficiency of the proper or natural quantity. The language suggested by the latter theory is the most convenient to adopt, although it is considered by many philosophers that the other explanation agrees best with the facts at present known. I shall therefore employ the terms positive and negative, to distinguish *glass electricity* from *resin electricity.*

The same simple materials will serve to develop another very important electrical law—namely, *that one kind of electricity cannot be produced without the other.* After the tube has been rubbed with the silk, or the wax with the flannel, taking care to keep the flannel or silk so folded that the rubbed part shall be as far as possible from the hand, let the feather be electrized, and when it has been repelled by the tube, let it be advanced towards the silk, and it will be attracted; the same will take place after it has been repelled by the wax on making it approach the flannel. Now as it was shown by a previous experiment that bodies when repelled by one electricity are attracted by the other, it is evident that the glass tube and the silk, and the sealing-wax and the flannel, are in opposite electrical states. In the case of the glass and silk, the former is positive and the latter negative; and in the case of the sealing-wax and flannel, the former is negative and the latter positive; which may further be shown by making the feather positive, by contact with the excited glass, and then bringing near it the excited flannel,—*repulsion* will be the consequence.

It is easy to see why the pith ball or feather should have been first attracted and then repelled by the glass:—they are first thrown into an opposite electric state by the mere proximity of the tube, and then attracted: being so small they can imbibe from the excited electric a sufficient quantity of its electricity to exhibit electrical phenomena, without much lessening the quantity on the glass; both are consequently *now* similarly excited, and hence by the law discovered by Du Fay mutually repel each other. When the sealing-wax is brought near, the case is altered, and the tendency of the pith ball or feather to advance towards it, is increased by their saturation with electricity of an opposite kind. From the circumstance also of their retaining their small electrical charges for some time after the exciting body has been removed, we see that air is a non-conductor as well as the silk by which they were suspended. On touching them, however, with the finger or with a rod of metal they immediately lose all signs of electricity, which shows that metals, and the human body, are powerful conductors. When bodies are confined on all sides by non-conductors they are said to be *insulated.*

The insulating power of atmospheric air, depends on its dryness and density; but as it is almost impossible to exclude moisture entirely, it is likewise impossible to preserve an excited body with its electricity undiminished for any great length of time. In proportion also as air is rarefied by the removal of superincumbent pressure, its power of confining electricity diminishes, till at last when the rarefaction is very great, it opposes scarcely any resistance to the passage even of very feeble electricity. This is prettily shown by drawing the air from a long glass tube, capped at each extremity by brass, by means of the air-pump, and then holding it to the prime conductor of an electrical machine in motion ; the electricity will be observed to pass through the partial vacuum, exhibiting streaks of pale blue light. Air in this rarefied state may therefore be classed among conductors. Among solids, gum lac is the best insulator, and silver and copper the most perfect conductors. It follows also as a necessary consequence, that the worst conductors are the best electrics, and vice versâ: but there is no substance in nature that can be said to be altogether impervious to electricity.

From what has been already said, sufficient may be gathered to understand the theory of electrical machines. They are of two kinds, the cylindrical and the plate machine. The former was suggested by the glass globes employed by Mr. Hauksbee, about the middle of the last century. The elements are few and simple. A glass cylinder mounted on an axis and furnished with a handle,—a cushion of leather stuffed with horse-hair, and fixed to a pillar of glass, furnished with a screw to regulate the degree of pressure on the cylinder,—and a cylinder of metal, or wood covered with tin foil, mounted on a glass stand, and terminated on one side by a series of points to draw the electricity from the glass, and on the other side by a brass knob. A flap of oiled silk is attached to the rubber, to prevent the dissipation of the electricity from the surface of the cylinder, before it reaches the points.

Fig. 1, represents a cylindrical machine.

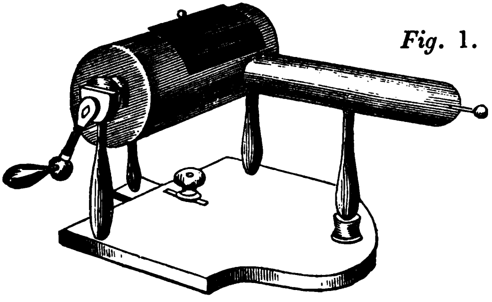
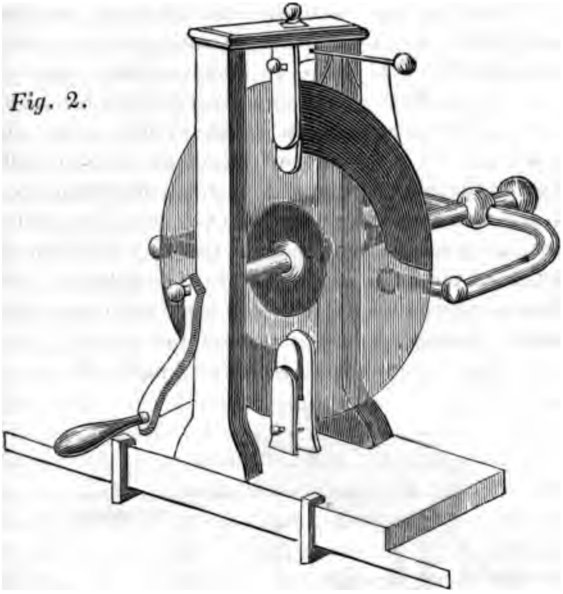


Fig. 1.

The plate machine is not so simple in its construction, and though it possesses some advantages over the cylinder, such as greater portability, and greater electrical development from an equal surface of glass, in consequence of both sides being exposed to the action of the rubber—yet, as it cannot be conveniently insulated, the negative electrical power cannot be so well exhibited. For the general purposes of experimental illustration, cylindrical machines are preferable.

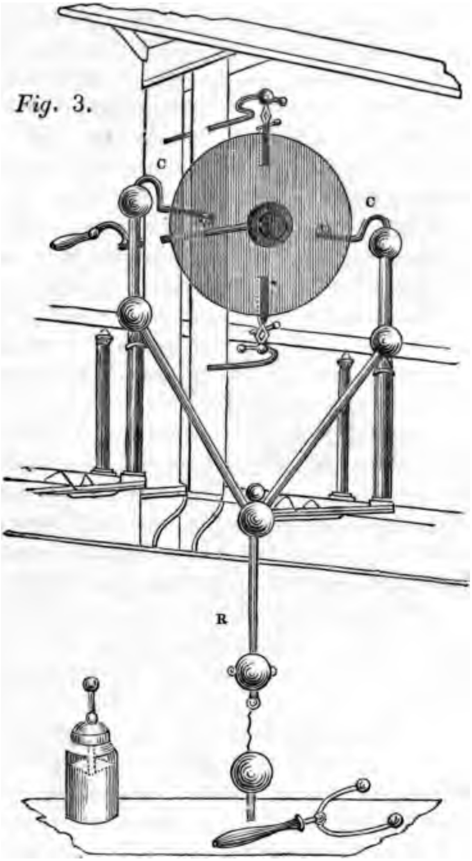
The plate machine is shown in *Fig*. 2.

Fig. 2.



There is one capital disadvantage attending the use of the plate machine, the glass is very apt to crack at the axis, particularly if it be incautiously held too close to the fire, in consequence of the unequal expansion by the heat; this crack gradually proceeds to the circumference and the machine is destroyed. Its extension may however be sometimes successfully checked by drilling a hole through the plate at the point of the crack. Dryness, rather than warmth of the air is requisite for the activity of the machine, it should therefore be kept in a dry room, and when about to be used, warmed if practicable by a current of warm air, rather than by direct exposure to the fire; by this means a more general and equal temperature may be given to it. The rubber or cushion is covered with a thin layer of an amalgam, formed by melting together equal parts of tin and zinc, and shaking the fused alloy in a wooden box, with twice its weight of mercury. If the mixture be carefully made it will when rubbed in a mortar, with a little lard, form a smooth paste, which when spread over the rubber will be found by its chemical action greatly to increase the development of electricity from the cylinder. Dr. Thomson recommends as the best proportions for making amalgam, zinc 8-5 parts, tin 7-25 parts, mercury 37-5, being in the ratio of the atomic weights, or chemical equivalents of the metals. Such a compound is however apt to crystallize and become hard.

Fig. 3 represents Dr. Hare's electrical machine, with a plate four feet in diameter, so constructed as to be above the operator. It is extremely convenient for the lecture-room, being never in the way and yet always at hand. The prime conductor is supported and insulated by means of wooden posts covered by stout bell-glasses, so that the summits of the latter are between those of the posts and the inner surfaces of



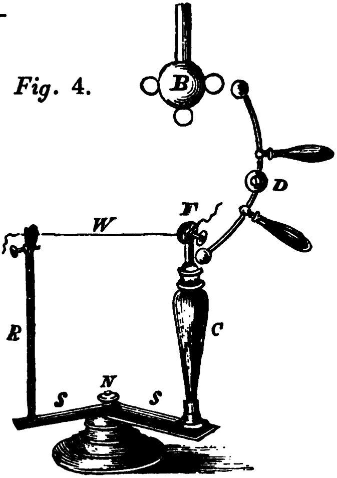
caps attached to the conductor. At cc are the collectors. R represents a sliding rod, which may be drawn out to such an extent as to be brought in contact with any apparatus placed under it upon the table. The machine is kept in motion by an assistant.

When the cylinder is set in motion it becomes positively excited, and the rubber consequently negatively: that is, according to the Franklinean language, which I shall continually adopt in these Lectures there is a transfer from the one to the other. The points carry off this positive charge to the conductor, and the action soon reaches its limit. For when the cushion has been exhausted to a certain degree, the same force of excitation will not supply any further quantity to the glass; to enable it to do so, it must be itself *replenished*, and as the earth is the great natural emporium of electricity,' the most obvious method of accomplishing this, is to establish a metallic communication between the rubber and the ground; when this is done an indefinite supply of electricity may be obtained.

By the usual method of working the electrical machine, therefore, we obtain supplies of positive electricity, and it is easy to see, that by reversing the order of arrangement, namely by connecting the prime conductor with the earth by a chain, and keeping the rubber insulated, we shall obtain an equal supply of negative electricity from the latter. That the quantity *is* equal may be proved by uniting the two conductors by a metal wire, in which case no sparks can be obtained from either, but if the wire be not continuous, a succession of sparks will appear at each interval as the machine is turned, plainly indicating the passage of a current from the one to the other.

Fig. 4 represents a battery discharger, for deflagrating wires, devised by professor Hare. Two brass plates SS, are fixed in a pedestal by a bolt N, about which they have a circular motion. On one of the plates, a glass column C, is cemented, surmounted by a forceps F; at the corresponding plate there is a brass rod R, furnished also with a forceps; between these forceps and those at F, the wire through which the electric charge is to be sent is stretched, which may be of various lengths, according to the angle which the plates SS, make with each other. The bottom of the pedestal is in communication with the exterior coating of a jar or battery, which is charged from the prime conductor B, and with which it is allowed to remain in communication. Now, it is obvious that in this case, touching the conductor is equivalent to touching the inner coating of the battery. However, by causing one of the knobs of the discharger D, to be in contact with the insulated forceps F, and approximating the other knob to the prime conductor, the charge will pass through the wire W.

Fig. 4.



You will also readily understand, that according to the theory of a single fluid, the spark that appears on presenting the knuckle to the negative conductor, is in fact passing from the ground through the body into the rubber, and not as from the prime conductor into the body through the knuckle; but it is impossible to distinguish any difference between these two sparks owing to the immense velocity with which electricity travels.

Biot's experiments relative to the distribution of Electricity, deserve to be mentioned. It had been demonstrated by Coulomb, that the quantity of electricity which a body was capable of receiving, depended on the *surface* and not at all on the *mass* of matter. Biot further proved that however highly a body may be charged, it will contain no more electricity, than may be removed by a plate of the same superficial extent. He suspended a spheroid presenting a metallic surface, by a silken thread, and electrified it; he then took two thin tin caps, furnished with insulating handles, and having carefully placed them over the spheroid, instantly removed them—they were found to have conveyed away the whole of the electricity. Again, an insulated cylinder furnished with a handle to turn it, was coiled round with tin-foil, having a silken thread attached to one of its extremities; it was then electrified;—on unrolling the foil the pith balls attached to the cylinder collapsed, shewing that the distribution was confined to the surface.

Coulomb was led to a conclusion of considerable importance, whilst investigating the state of electricity on the surfaces of bodies. On electrifying a circular metallic plate, he found that the accumulation of electricity was considerably greater at the circumference than about the centre. The intensity at the extremities of bodies of a cylindrical or prismatic form was still further augmented, and the more so as their length bore a greater proportion to their breadth. In a cylinder thirty inches long and two inches in diameter, the electrical intensity at the ends was to that in the middle, or at any other part more than two inches from the extremity as 2·3, to 1. Reasoning from these facts it would appear that the intensity of electricity at a *point*, should be exceedingly great, and that the point would condense into itself nearly the whole charge contained in the body. It is accordingly found by experiment, that the intensity of the electricity at the apex of a point is so great, and the tendency of the fluid to escape so powerful, that it is impossible to obtain any considerable accumulation in bodies with sharp extremities—the opposing non-conducting surface of the air being entirely overcome.

This dispersive property of points is made the basis of a variety of amusing experiments. Currents of air invariably attend the discharge of electricity from pointed bodies, and these currents tend powerfully to increase the dissipation, by bringing a continued succession of particles of air in contact with it. Orreries, mills, and machinery of various kinds are set in motion.

The stream of electricity given off at the points removes the pressure which the fluid would have exerted on that side, if no efflux had taken place: the wires therefore to which the points are attached have a tendency to move in an opposite direction, by the action of the fluid on the other side. This dispersive property is much diminished by increasing the number of the points, or by their being surrounded by other parts of the conducting body equally prominent.

Fig. 5 represents a model of a water-mill for grinding corn turned by a current of electricity. A is the wheel, B the cog-wheel on its axis, C the trundle, and D the running mill-stone, on the top of the axis of the trundle. To set this machine in motion by electricity, place it near the prime conductor, in which is inserted a crooked wire, terminating in a sharp point. Let this point be directed to the uppermost side of the wheel A. On putting the machine in motion, the current of air attending the electricity which issues from the point, will turn the wheel, and consequently all the other working parts of the mill.

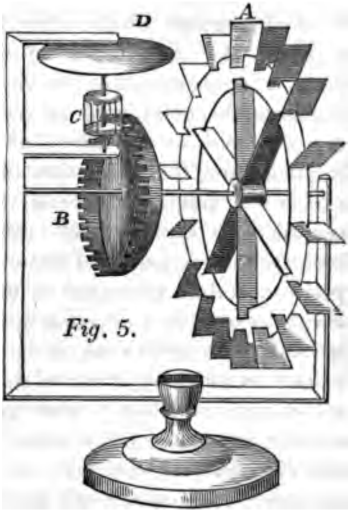
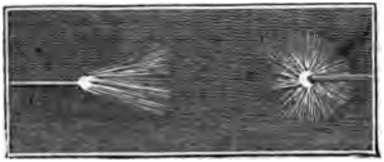


Fig. 5.

When the transfer of electricity takes place between smooth surfaces of a certain extent, no difference can be perceived in the nature or appearance of the spark, whatever the position of the negative surface may be; but in the passage of electricity through points, it is different. When the fluid is escaping, the luminous appearance is that of diverging streams like the filaments of a brush, forming what is called ***a pencil of light***, but when it is entering a point it is much more concentrated, having then the appearance of a ***star*** with radii branching out in all directions.

The brush and star are represented in *Fig.* 6.

Fig. 6.



If the theory of Du Fay be adopted, we must consider the appearance of the pencil as arising from a double current of vitreous electricity issuing from the point, and of resinous entering; while the star will be the effect of the irruption of the resinous, and the absorption of the vitreous—at all events the difference between the two luminous appearances is very marked, and appears strongly to indicate the emanation of some material fluid from the positive, and its reception by the negative point. It may also serve as a criterion in many instances, of the species of electricity which is passing from one conductor to another, if not of the absolute direction of its motion. When a *star* appears on presenting a point to an electrified body, it may be known that the electricity of that body is positive, while on the contrary, a luminous brush will indicate that the body is negative. It may further be remarked that a spark may be more readily obtained from a positive, than from a negative point. The influence of points in rapidly and silently drawing off electricity, may be elucidated, by holding a pointed wire to the prime conductor of a machine ; it will be observed that no spark will pass either into it, or into the knuckle, or a brass ball in its neighbourhood. And if a pointed wire be attached to the conductor of a machine in vigorous action, the great augmentation of the intensity of the electricity will cause it to pass off into the air, which, in obedience to the usual laws, will be rapidly repulsed, causing a stream of wind, which has been called the *electrical aura*, sufficiently strong, to blow out a candle held near it.

We now come to consider a very important electrical law, preparatory to the examination of the theory of the Leyden phial—namely, the law of *induction.* And it will be found as we proceed, that the clear understanding of this law is essential to the comprehending of many electrical phenomena. The disturbance of the electric equilibrium by excitation, has been illustrated by the action of the common machine, but there is found to be another source of development. Active electricity always tends to induce the opposite electrical state in bodies that are near it. It is impossible to induce one electrical state in any body, without at the same time producing the opposite state; and, adopting the simpler or Franklinean theory, we must suppose that accumulation in one part can be effected in no other way, than by withdrawing electricity from another part; nor can it be taken from one, without being received by the other; so there is always an equal quantity of positive and negative electricities. But those that prefer the more complex theory, must conceive equal quantities of vitreous and resinous electricities to be obtained by the decomposition of the natural share resident in the body. If the bodies subjected to inductive influence are *non*-conductors, although the tendency still exists, yet in consequence of the immobility of the fluid no visible change can be produced; but in proportion as the body opposes less resistance to the fluid, the operation of the disturbing force becomes sensible.

The general principle of electrical induction may be illustrated by a few very simple experiments. Provide a thin brass wire terminated at each end by two pith balls, and let it be balanced on its centre on an insulated point. Now take a glass tube, and having excited it in the usual manner, bring it near one of the pith balls, and it will be attracted; the inference is, that it has become negative; and this is proved to be the case by bringing near it a piece of excited sealing wax, by which it will be repelled. Now bring the wax near the other ball and it will be attracted, by which it is evident that the two balls have been brought into opposite electrical states by bringing an excited electric in the neighbourhood of *one;* in other words, the proximity of a positively excited body to one end of the wire, has driven a considerable portion of its natural electricity to the other end, and the former is consequently minus. This polar arrangement may be extended to any number of insulated conductors, but the accumulation of either electricity is of course weak, being confined to the decomposition of the natural quantity existing in them. When we have described the nature of the gold leaf electrometer, we shall notice another very beautiful illustration of the property of induction.

If a series of pith balls suspended in pairs from an insulated conductor, are exposed to the influence of a positively excited electric, all the pairs but those in the centre, immediately diverge; indicating the electrical state of the parts from which they are hung. Those at either extremity diverge most, those in the centre not at all, being in the plane of neutrality. If the electrical condition of these several pairs be now examined, it will be found that those nearest the exciting glass are negatively charged, and those furthest off positively; and as there is no communication of electricity from the excited substance to the conductor, the phenomena must result from an influence exerted on its natural electricity.

If the exciting body be *not* an electric, but a globe of metal positively charged, the first general appearances will be similar, but there will now be observed a *re-action of the conductor on the globe*, followed by a series of smaller adjustments till an equilibrium and slight increase of intensity is attained; the induced negative electricity on the near side of the insulated conductor, attracting the excess of positive in the globe into a concentrated state, and vice versâ.

If instead of employing in this experiment an insulated conductor, a long one in communication with the earth be substituted, the inductive effects will be very considerably augmented, for the further the fluid is expelled by an electrified body, the greater will be the re-action of that fluid. From such an arrangement therefore, a spark may be obtained, by touching the remote end.

The important application of the principle of induction, is that by which a great accumulation of electricity is obtained in a small place, with but a small disposition to escape. The following experiment will illustrate this :—provide two circular metallic plates of equal size; attach one by a chain to the prime conductor of a machine, and insulate the other by placing it on three glass legs covered with shell-lac varnish. Now, when the machine is set in motion observe what takes place. The fluid naturally contained in the lower plate will be repelled by the fluid communicated to the upper; it will therefore leave the upper surface, and occupy the lower. On making a communication with the earth, this accumulation will be carried off, and the whole plate thus rendered minus or negative. This is not all; the action of this negative electricity will bring a fresh portion of positive from the prime conductor into the upper plate, as is proved by the falling of the ball of the electroscope; thus the re-action of one plate on the other is shown to increase its capacity, and to render a large portion of electricity latent.

Of course the quantity of electricity given out by the lower plate, can never be exactly equal to that with which the upper is charged, because of the intervening non-conducting stratum of air, but the nearer the plates are brought together, the nearer will be the approach to equality. This is a case of accumulation by induction, and the following are the practical consequences to which it leads. The most obvious that presents itself is that of covering a plate of glass, (which of course will not interfere with the inductive process,) with tin foil, leaving a sufficient margin to prevent the transference of electricity from one side to the other. Suppose a pane of glass to be thus coated, mounted on a stand, and furnished with a pair of pith ball electroscopes: charge one side positively, and let the other side communicate with the earth, the ball on the charged side will of course immediately stand out, but the other ball will remain uninfluenced. In proportion however as the electrical charge becomes dissipated, the pith ball will slowly descend. Now break off the communication between the unexcited side and the earth, the ball on the excited side will rapidly fall till it has reached about half its first elevation, at the same time the other ball will be observed to rise to an equal height; touch that ball with the finger, it will suddenly fall, and the other will rise as much: remove the finger and the reverse will take place, that is, the excited ball will fall, and the other rise, then both will slowly begin to descend. This process may be repeated many times with both balls before the balance between the sides is accomplished. If instead of this gradual discharge a direct communication be made between the two coatings by means of a metallic wire, the neutralization is instantaneously effected with violent impetus, giving rise to the electric shock. This experiment, which from the principles before developed, you will find no difficulty in understanding, constitutes the analysis of the theory of the Leyden phial.

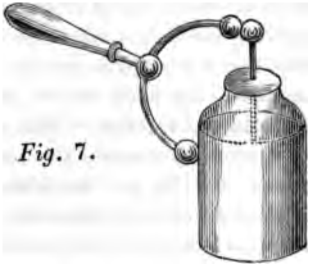


Fig. 7.

This instrument is merely a pane of glass coated with tin foil, and doubled into the form of a jar for portability and convenience. It derives its name from the town in which it was invented, and the circumstances attending its discovery have already been mentioned. A communication is established between the interior of the jar and the prime conductor of the machine, and the accumulation is of course accomplished by induction. The inside of the jar becomes positively charged, while at the same time an equal quantity of the natural electricity of the outside is expelled. The accumulation in the inside of the jar depends on a free channel being provided for carrying off the electricity of the outside; this is proved by insulating the jar, in which case it will be found impossible to charge it. If, however, while it is on the insulating stool it be touched from time to time with the knuckle, a spark will at each time be seen, and then the jar will become charged; or, if the knob of a second jar be applied to the outside coating, that jar will receive a fair charge, and this if insulated will give a charge to a third, and so on, provided the last communicate with the earth.

A Leyden phial may be charged by the transference of its own natural electricity, in the following manner: suspend it from the prime conductor of a machine, and connect its exterior coating by means of a wire with the rubber or insulated negative conductor; after a few turns it will be found charged; and as every means of deriving electricity from the earth is cut off, it is evident that the positive charge the interior of the jar has acquired, has been derived from the electricity driven off from the exterior. This experiment further shows in a striking manner the *non-conducting powers of glass;* for the two conductors of the machine are separated from each other by the thickness of the glass jar alone; a considerable accumulation of electricity nevertheless takes place, which the smallest particle of conducting matter would effectually prevent: it does sometimes happens that a powerful charge neutralizes itself through the glass, but this is by actually *perforating* the jar, in which case a small hole is perceptible, and the jar becomes useless.

The power of accumulation by induction diminishes rapidly as the thickness of the non-conducting substance increases; hence, in making choice of jars for electrical purposes, those that are uniformly thin, should be selected, yet not too thin, for in that case the accumulation would be sufficiently intense to force a passage through the glass.

That the outer and inner coatings are in opposite electrical states is proved in an amusing manner, by attaching a bent arm, terminated by a brass ball to the outer coating; the ball being on the same level with the ball of the inner wire, and suspending a pith ball by a silk thread between the two, it will be alternately attracted and repelled by each, till the jar is silently discharged.

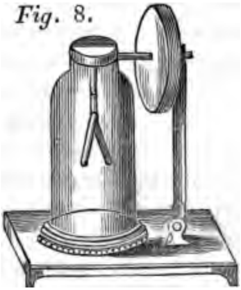
The Leyden phial as we have been hitherto considering it, is said to be positively charged, but it is evident that by operating in a reverse manner, we may communicate to it an opposite or negative charge. We have only to place it on an insulating stand, and establish a connexion between the outer coating and the machine, and the inside and the earth; the outside will then be positive, and the inside negative. If we take two equal sized jars, one charged positively, and the other negatively, and place them on two insulating stands, then make a communication between the two knobs by means of an insulated metallic rod, no explosion will ensue, although the condition for producing such are apparently complied with, the two being in oppositely electrical states; but if at the same time the two outer coatings are connected, an explosion will immediately take place, and both jars will be reduced to their natural state.

It will doubtless be imagined by those who are witnessing these experiments for the first time, that in a charged electrical jar, the accumulation is extended over the tin foil coatings, as it is by connecting these together by the discharging rod, that the explosion and spark is produced, but the following experiment will show that this is not the case. Let a jar be provided with moveable coatings of thin sheet tin, and let the wire which communicates with the interior pass through a glass tube to serve as an insulating handle to remove the coating. Now charge the jar in the usual manner, and remove first the inner coating, then turn the jar on its mouth on a plate of glass, and remove the outer case, both may be handled without giving the slightest shock, or affording the least proof of the presence of electricity: replace them on the jar again, and on making the connection in the usual manner with the discharging rod, the explosion will pass. A fresh pair of coatings may even be applied to the jar, with the same result, the explosion will pass. This proves that the electrical accumulation is on the surface of the glass, and that the coatings act merely as conductors, serving to collect the diffused electricity to one point at the moment of discharge.

Having thus described and exemplified the important law of induction, I proceed to notice some of those instruments that have been devised for rendering evident very small traces of electricity. These instruments are called electroscopes, electrometers, condensers, and multipliers or doublers. The simplest form of the first of these is the pith ball electroscope, which has been sufficiently alluded to in the former part of this lecture. Bennet's gold-leaf electrometer is the next worth notice; it is far more delicate than the pith balls; in its most improved form by the late Mr. Singer, it consists of a glass cylinder, cemented on a brass plate, and covered by a brass cap, a glass tube about four inches long and a quarter of an inch internal diameter, covered both on the inside and outside with sealing-wax, is fixed in the centre of the cap, and a wire one-twelfth of an inch thick, and five inches long, is passed through its axis, so as to be perfectly free from contact with any part of the tube, in the middle of which it is fixed by a plug of silk. A brass cap is screwed on the upper part of this wire, which serves to keep the atmosphere from free contact with the outside of the tube, and also defends the inside from dust: to the lower end of the wire two parallel slips of gold leaf are attached. The parts of the instrument are put together quite dry, and all the joinings secured by wax cement, and the glass covered by lac varnish. The object of these arrangements is to secure perfect insulation for the wire and gold leaves. The action of this instrument depends entirely upon the principle of induction, as will be seen by attending to the method of using it. Let a piece of sealing wax be excited by friction, and brought near the cap of the instrument; the electric equilibrium of the whole metallic surface will be disturbed; the brass plate will become positive, and the gold leaves will diverge from being negative. While the wax is still near, let the plate of the electrometer be touched by the finger, and what will be the result? The gold leaves will be restored to their natural state—not so the cap—*it* will still retain an excess of positive electricity by the proximity of the negatively excited electric; if therefore, the finger be first removed from the instrument, and then the wax withdrawn, the whole plate will be left with a considerable positive charge, which will diffuse itself over the whole metallic surface of the electrometer, and produce a divergence in the leaves which will last for a considerable time. The approach of any similarly electrified body will increase the divergence of the leaves; but a body in an opposite state will have a contrary effect, and diminish their divergence. Thus this simple instrument is not only made to discover small quantities of electricity, but is rendered exceedingly useful in indicating the kind of excitement.

It may be rendered still more delicate, by opposing to its upper plate another, which is in communication with the earth, and in this form it constitutes the instrument called the condenser; the two plates are usually placed vertically, the insulated disk being connected with the cap of the electrometer and the uninsulated one moving round a joint fixed in the foot, and thus capable of being turned back and removed from the other.

Fig. 8.

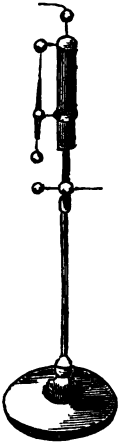


When this instrument is to be employed for the detection of very feeble electricity, the two plates are brought as close as possible to each other, without coming into actual contact. This proximity may be attained by dropping on one of the plates three spots of sealing wax, and then bringing them together; the sealing wax will keep them at a sufficient distance from each other, and being a non-conductor will not interfere with the result. The substance, the electricity of which is to be examined, is brought into contact with the plate connected with the instrument, which receives its electricity, and by the laws of induction, the other plate will at the same time receive an equal quantity of the opposite kind; this, by re-acting on the first will increase its quantity, and by this means the gold leaves may be made to diverge with a quantity too feeble to affect them under the simpler form of the electrometer. Instruments called doublers have been constructed on analogous principles, by which very small portions of electricity communicated to a part of the apparatus, may be continually doubled, until it becomes perceptible by the electroscope: but in researches of a very delicate nature, the indications of these instruments are very little to be relied on, it being ascertained that the mere working of the mechanical part of the arrangement, will develop electricity, although none has been previously communicated to it.

The electropolar state of a conductor under induction, may be shown in a very instructive manner, by two gold-leaf electrometers. Let two of these instruments be placed on a table about eighteen inches apart, and lay a wire across their caps, then bring an excited glass tube near one of them, *both* will of course diverge. Now remove the wire, and then the tube, and examine the electrical state of the gold leaves of each. That pair which was nearest the excited electric will be found negative, and the other pair positive. Now take another wire furnished with a handle of gum lac for insulation, and lay it across the caps of the instruments, both will collapse; showing first that two opposite electrical states were first given to the wire by the glass tube, and, secondly, that these electricities were co-equal.

I shall conclude this lecture with the description of a very useful little electrical instrument, devised by Mr. Snow Harris, of Plymouth, for registering the exact quantity of electricity given to a Leyden phial from the machine; it is called the unit jar.

Fig. 9.



It consists of a small inverted Leyden phial, supported and insulated by a slender glass rod, which is covered with varnish, and fixed in a wooden frame. The wire from the inner coating of this small jar is terminated by another wire at right angles to it, and furnished with a brass ball, and the outer coating is provided with another arrangement of wires terminated by a brass ball, and so adjusted as to be moveable by means of a slide or screw, by which the interval between the balls can be increased or diminished. From the bottom of the outer coating another wire proceeds, which is intended to communicate with the ground, by being held in the hand or otherwise—this jar is charged in the usual manner, and discharged by a spark passing between the two brass balls. Now it is quite clear that successive sparks passing through the same interval must be caused by equal quantities of electricity; when therefore the interior of the jar is in communication with the prime conductor of a machine in action, the terminal outside wire in contact with the interior of a large Leyden jar or battery, and the balls arranged at a certain distance, if the whole be quite dry, it is very easy to measure off any number of charges into the large jar, and thus obtain any required quantity of electricity for any particular purpose. The effect of the spark passing between the two brass balls of the unit jar, will under these circumstances be merely to neutralize its own coatings, without affecting the state of the large jar, for at the first charging of the unit jar, the fluid that is repelled from its exterior, enters the large jar, and the former becomes negative by induction; the same is repeated in the second and third charge.

LECTURE II.

In the present lecture I shall first direct your attention to a very useful instrument which is often employed as a source of permanent electricity, and which is peculiarly applicable to the chemical laboratory, as a substitute for the electrical machine. This instrument is the *electrophorus;* it derives its efficacy from the principles of induction, which it serves in a very striking manner to illustrate.

It was invented in the year 1774, by Professor Volta. It consists of three parts—a cake of resinous matter composed of equal parts of shell-lac, Venice turpentine, and common resin, melted at a gentle heat; the conducting plate or sole, which is a circular metallic plate with a rim about a quarter of an inch deep, into which the composition is poured; and the cover, which is of metal, provided with an insulating handle. The mode of using it is as follows: the cake is excited by gentle friction with a piece of dry fur, it thus becomes negatively electric. The cover is then placed on it. By induction, the lower surface becomes positive, and the upper negative; and on raising it from the cake it is found very feebly electrical. Let it now be replaced on the cake, and the finger laid on the upper surface, a small spark will be observed to pass; the electrical equilibrium of the upper surface will be restored; and, on raising the cover a second time by its insulating handle, it will give a considerable spark of positive electricity, which may be imparted in the usual manner to a Leyden phial. The operation may be repeated an indefinite number of times; for since the whole effect is due to induction, the cake loses nothing by the process; it becomes therefore a magazine of electricity, and may be kept in action many months, provided it is kept quite dry; but when the power is lost, it may be quickly and easily restored by rubbing.

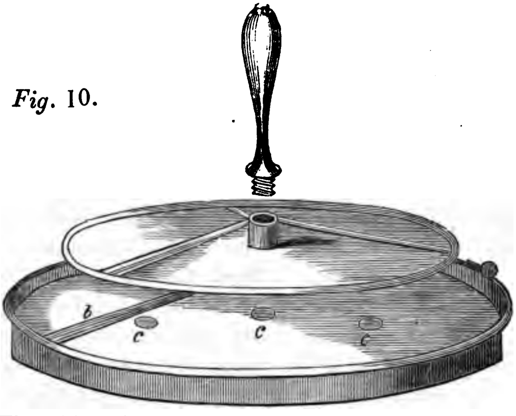
That the electricity developed by the cover is *not due* to the resinous cake *directly*, may be rendered obvious, by considering that there is no actual contact between the resin and the cover; such being prevented by the small irregularities on the surface of the former. The cover is then in the most favourable state to become electrical by induction, when its upper surface is touched by the finger, and thus rendered uninsulated.

With the electrophorus, the increased capacity of a conductor for electricity, when under the influence of induction, may be shown more satisfactorily than with any other instrument. Indeed the cover represents one end of a conductor of an indefinite length. When it is first laid on the resinous cake, its lower side becomes positive, and its upper negative, and upon touching the surface with the finger it instantly *acquires* electricity, and becomes positive, giving on removal, a positive spark to any conductor.

The following experiment has been described as proving that the quantity of electricity given *out* by the cover, is exactly equal to the quantity received from the finger. When the plate has been laid on the excited cake, let it be touched by the knob of a Leyden phial, then touch the top of an electrometer with the knob of the phial, a negative divergence of the leaves will be the result. Now raise the cover and immediately present it to the knob of the jar, a spark will pass; and upon presenting the jar a second time to the electrometer, the leaves will collapse; showing the annihilation of the former negative by the latter positive charge.

An apparently useful modification of the electrophorus of Volta, is described by Mr. John Phillips, in the eleventh number and second volume of the London and Edinburgh Philosophical Magazine.

Fig. 10.



The object is to avoid the trouble and tediousness of establishing a communication between the insulated cover and the earth, by means of the finger, when electrical accumulation, or sparks in rapid succession is the object. Three methods are proposed:—The first consists in raising from the metallic basis, above the edge of the resin, a brass wire and ball, to which the edge of the cover, or a brass ball upon it may be applied. This method is stated to act very well, especially with small covers, which can with ease and certainty be directed to any particular point of the sole. The second is, to fix a narrow slip of tin foil *b* quite across the surface of the resinous plate, and unite it at each end with the metallic basis. This construction is said to answer perfectly and instantaneously, and to be especially convenient with large circles, the covers of which, though uneven, will thus be sure to touch some conducting point. The third method is to perforate the resinous plate quite through to the metallic basis, at the centre and any other points, and at all those points to insert brass wires, *c c c* with their tops level with the resin. Mr. Phillips remarks, that though, "to those who have not studied the electrophorus, it may appear extraordinary that the wires or the tin foil at the surface of the resin, do not, when the cover is uplifted, reduce its electricity to the natural state of equilibrium; yet this wonder will cease when it is considered that while the cover touches the excited electric, and at the same time a body conducting to the earth, it is put into a state of *forced equilibrium* with the electric, by the induction of that body; and that on being separated from it, and at the same time from bodies conducting to the earth, the conditions of this equilibrium are more and more impaired the further off the cover is removed. Therefore at very small distances from the electric, the cover has no sensible tendency to communicate with any conducting body; (as may be proved by electroscopes) and at greater distances when the conditions of equilibrium are proportionately diminished, the striking distance of the cover is not equal to the interval between the points supposed to communicate." The latter of these three methods is preferred.—An instrument on this principle with a cast iron basis 20·5 inches in diameter, resinous surface 19·75 inches, and cover 16·25 inches, is described as yielding loud and flashing sparks two inches long, and speedily charging considerable jars. The cover can be easily charged from fifty to one hundred times a minute, by merely setting it down, and lifting it up as fast as the operator chooses, or as the hand can work. In charging a jar or plate, one knob of the connecting rod is placed near the insulated surface of the jar, and the other some inches above the cover, being alternately lifted up, and set down, the jar is very quickly charged.

It appears that Dr. Hall, in the year 1708, was the first person who noticed electric light. He observed it first, when pieces of amber were rubbed with flannel; and afterwards in diamond, shell-lac, and sealing wax when rubbed. This light he compared to lightning. The pencil and star spoken of in the last lecture, as characterising positive and negative electricity, were first described by Mr. Stephen Gray.

When electric light is examined by a prism, it is found to be composed of the same seven rays as common light: but the proportion of these rays, and the consequent colour of the light varies. Dr. Wollaston found that the prevailing tint of colour varies according to the different substances through which the sparks pass, or to the nature of the surface from which they emanate, or by which they are received. Thus, in passing from one polished metallic surface to another, they are white, but when drawn by the knuckle from the prime conductor, violet; they are *green* when taken from the surface of silvered leather; yellow when taken from finely powdered charcoal; and purple when taken from the greater number of imperfect conductors.

When a given quantity of electricity occasions a spark in passing from one conductor to another, it is always more brilliant the smaller the size of the body from which it is drawn; hence the sparks that are taken from the brass knob at the end of the conductor, are brighter than those taken from the conductor itself. The most vigorous sparks are generally white, as are also short ones; but a very long spark is usually purplish, especially towards the middle. When a spark is taken in an atmosphere of carbonic acid, it is white and vivid; but in hydrogen, it is faint and red. This difference is not occasioned by the chemical difference in these two gases, but by their great difference in density; carbonic acid being twenty-two times heavier than hydrogen. In proportion as the medium is more rare, its conducting power increases, and consequently a smaller intensity of electricity is required for the production of light. When air is rarefied by the air pump, the passage of electricity is rendered sensible by streams or columns of diffused light, exhibiting at times coruscations resembling those of the aurora borealis. A spark which, in the open air does not exceed a quarter of an inch long, will appear to fill the whole of an exhausted receiver four inches wide and eight inches long. In the former case it will usually be white; in the latter, feeble, and the colour violet, unless the air is exceedingly rarefied; in which case it will be pale green. A curious appearance is presented when sparks are taken in a vessel filled with the vapour of ether. If the eye be placed close to the tube, they appear green; but when viewed at a considerable distance, they have a red tinge.

It is impossible to help observing the analogy between electric light, and the light emitted by burning bodies; neither contains *always* the same rays that exist in solar light. When the spark is feeble, only the most refrangible rays appear; when it is strong, all the rays appear together of a dazzling whiteness. The electrical brush is always violet; and when a spark is made to pass through a torricellian vacuum, (that is, the vacant space above the surface of the mercury in the barometer,) made without boiling the mercury, the colour is indigo. It is precisely the same in combustion. When it is feeble, the colour of the light is blue; but when it is strong, the colour is white.

The light which appears during the passage of electricity, was at first supposed to be due to the accumulation of the fluid itself, and, in fact, was the fluid in a condensed state. It is now the general opinion that it is owing to the condensation of air. It has been shown that electricity produces a current of air which may very plainly be felt with the finger. From this, and from the immense velocity with which it travels, it is evident, that as it passes through the air, it must produce amongst the particles a sudden and violent compression. Now, air, when suddenly compressed sufficiently, gives out light and heat, and the colour of the light depends on the rapidity and extent of the compression. The following experiments on this interesting branch of electricity, were made by Sir Humphry Davy, and published in the Philosophical Transactions for 1822. By boiling mercury in a bent barometer tube for some time, he succeeded in forming a torricellian vacuum, *quite* free from air, but in which the vapour of mercury was quite sensible; a platinum wire was passed through the closed end of the tube, and hermetically sealed in it. In all cases, when the mercurial vacuum was perfect, it was permeable to electricity, and was rendered luminous either by the common spark, or the shock from a Leyden jar, and the coated glass surrounding it became charged. But the degree of the intensity of this phenomenon, depended upon the *temperature.* When the tube was very hot, the electric light appeared in the vapour of a bright green colour, and of great density. As the temperature diminished, it lost its vividness; and when it was artificially cooled to 20° below zero, it was so faint as to require considerable darkness to be perceptible. In all cases when the minutest quantity of rare air was introduced into the mercurial vacuum, the electric light changed from green to sea-green, and by increasing the quantity of air, from sea-green to blue, and from blue to purple. And when the temperature was low, the vacuum became a much better conductor.

A vacuum being made by means of fused tin, the electric light at temperatures below 0° was yellow, and of the palest phosphorescent kind, requiring almost absolute darkness to be perceived: and it was not perceptibly increased by heat.

Davy also tried to form a vacuum above boiling olive oil, and above chloride of antimony, which boils at about 388°. The light produced by the electricity passing through the vapour of the chloride, was much more brilliant than that produced by passing through the vapour of the oil; and in vapour of oil it was more brilliant than in vapour of mercury. The light was pure white in the vapour of the chloride, and of a red inclining to purple, in the vapour of the oil; and in both cases, permanent elastic fluid was produced by its transmission.

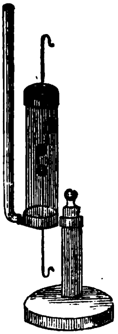
When the temperature was diminished, the electrical light, (transmitted through vapour of mercury) diminished also, till the temperature was reduced to 20°. But between 20° and —20° it seemed stationary.

Unless the machine was very active, no light was visible during the transmission of the electricity; but that the electricity passed was evident, from the luminous appearance of the rarefied air in other parts of the system. When the machine was in great activity, there was a pale phosphorescent light above, and a spark on the mercury below, and a brilliant light in the common vacuum. A Leyden jar weakly charged, could not be made to transmit its electricity by explosion through the cooled torricellian vacuum, but the electricity was slowly dissipated through it—and when strongly charged, the spark passed through nearly as much space as in common air, and with a light visible in the shade. At all temperatures below 200°, the mercurial vacuum was a much worse conductor than highly rarefied air, and when the tube containing it was included in the exhausted receiver, its temperature being about 50°, the spark passed through a distance *six times* greater in the Boylean, than in the mercurial vacuum.

From these well contrived experiments, it seems proved, that electricity is capable of passing through an imperfect vacuum, and that the light which appears, depends on the vapour or air through which it passes, consequently, if the vacuum is *absolutely* perfect, no light whatever will be produced.

The following experiment was devised by Mr. Kinnersley, of Philadelphia, to show that air is violently compressed by the passage of an electric spark through it.

Fig. 11.



A glass tube, ten inches long, and two inches in diameter, is closed air tight at both its ends by two brass caps; a small glass tube, open at both ends, is passed through the upper cap, its lower end being plunged into a little water at the bottom of the larger tube. Through the middle of each of the brass caps, a wire is introduced, terminating in a brass knob within the tube, and capable of sliding through the caps, so as to be placed at any distance from each other. If the two knobs are brought into contact, and a Leyden jar discharged through the wires, the air within the tube undergoes no change in volume; but if the knobs are placed at some distance from each other, when the jar is discharged, a spark passes from one knob to the other. The consequence is a sudden rarefaction of the air in the tube, shown by the water instantaneously rising to the top of the small tube, and then suddenly subsiding; after which it gradually sinks to the bottom of the tube, and the air slowly recovers its original volume.

It is only when the electric fluid is impeded in its course by imperfectly conducting particles, that it is attended with light; and such is the extreme velocity with which it is transmitted, that the sparks appear to take place at the very same instant, along the whole line of its course. This is shown by pasting slips of tin foil in any shape upon a pane of glass, and connecting one of its ends with the prime conductor, and the other with the earth, the whole device will be visible at the same moment in the dark, in a vivid and continuous line. A metallic chain also, the links of which are in apparent contact, appears illuminated, while conveying a charge of electricity.

When a very long spark is drawn from the prime conductor of a powerful machine in vigorous action, it will not be straight, but take an angular or zigzag course, like a flash of lightning, such as indicated by

*Fig.*12.

This is occasioned by the particles of conducting matter it meets with in its course, such as moisture suspended in the air.

Winterl, Ritter, and most of the early German electricians, maintained the opinion, that electric light is of the same nature with fire, and is formed by the union of the two electricities. Dr. Thomson who is an advocate of the hypothesis of *two* fluids, in speaking of this part of the subject, says—" Every person who has seen the spark must be aware, that the passage is so instantaneous, that it is impossible to say from which point it proceeds, or to which it goes. If the spark is long, that is, if the distance between the two knobs between which it passes, is considerable, the presence of the two kinds of electricity may be at once observed. Suppose one of the knobs attached to the prime conductor of a machine, and the other attached to a conducting body, connected with the earth—the portion of the spark nearest the prime conductor of the machine, exhibits all the characters which distinguish positive electricity; while the portion nearest the knob exhibits the characters of negative electricity. There can be no doubt therefore, that every spark is composed of the two electricities.* When two charged bodies are placed within the striking distance, no spark will pass, unless the one body is charged with positive, and the other with negative electricity. The two electricities are attracted towards each other, advance at the same instant, from each of the charged bodies, and uniting together somewhere between the knobs, all symptoms of electricity are at an end. When a spark is short, the whole distance between the knobs through which it passes is equally illuminated. But when it is long, those portions of it which are next the knobs, are much brighter than towards the centre of the spark. Near the knobs the colour is white, but towards the centre of the spark, purplish. Indeed if the spark is very long, the middle part is not illuminated at all, or only very slightly. Now, this imperfectly illuminated part, is obviously the spot where the two electricities unite; and it is in consequence of this union, that the light is so imperfect. From all this it is obvious, that both the electricities when in an insulated state, are capable of giving out a brilliant light; consequently the electric spark cannot be owing to the two electricities combining together.

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* NOTE.—Much as the Franklinean hypothesis recommends itself by its simplicity, there are strong points in favour of the theory of Du Fay. Both will briefly be noticed at the conclusion of this lecture.

"Whoever has observed the passage of long sparks from one body to another, cannot but have remarked, that the place where the light is the least, or where there is an interval of no light, lies much nearer the negative than the positive knob. In general, about two-thirds of the spark consist of positive, and one-third of negative electricity. The cause of this difference is inexplicable."—*(Thomson on heat and electricity)*.

Dr. Hare in noticing this passage, observes: "although the learned and ingenious author does not state what differences there are between the different portions of the spark, and wherefore, if any exist, he can without a petitio principii, assume that they are such as to justify his conclusion. He proceeds to allege, that there can be no doubt every spark consists of two electricities; which issuing severally from their respective knobs, terminate their career by uniting at the non-luminous portion of the spark, which is at a distance from the negative knob of about one-third of the interval. Upon these grounds he infers that the positive electricity occupies two-thirds of the length of the spark, the negative one-third.

"I presume that, agreeably to the theory which supposes the existence of two fluids, when the equilibrium between oppositely excited surfaces is restored by a discharge, whether in the form of a spark or otherwise, there must be two jets or currents passing each other; the one conveying as much of the resinous, as the other does of the vitreous electricity. Of course no part of a spark can be more negative than it is positive, or more positive than it is negative. Upon this ground, a suggestion of the same author, that the diminution of light near the middle of the spark, results from the combination of the different fluids at this point, appears to me injudicious, since there is as little ground for supposing the union of the fluids to take place there as elsewhere. But admitting that the union does take place as supposed, is this a reason for the observed diminution of light? If when isolated, either fluid is capable of emitting a brilliant light, should not their co-operation increase the effect? If, after their union, they do not shine, it can only be in consequence of their abandoning at that moment all the light with which they were previously associated. It cannot be imagined that the light accompanying one, should neutralize that accompanying the other.

"In deflagrating by voltaic electricity, a wire of uniform thickness equally refrigerated, the most intense evolution of heat and light is always midway.

"In truth, the theory which the learned author sanctions, requires two postulates so irreconcilable, that unless one is kept out of view, the other cannot be sustained. It requires that the fluids should exercise intense reciprocal attraction, adequate to produce chemical affinity, and of course enter into combination when they meet, and yet rush by each other with inconceivable velocity, and not only through the air, but also through the restricted channel afforded by a small wire. If the fluids combine at a point intervening between the surfaces from which they proceed, what becomes of the compound which they form? Is it credible that such a compound would afford no evidence of its existence? But again how are two surfaces, the one previously deprived of a large portion of the negative electricity naturally due to it, the other made as deficient of the positive fluid, to regain their natural state? By a combination midway, the resinous and vitreous surcharges might be disposed of, but whence could the vitreous and resinous deficiences be supplied?"—*(Experimental observations.)*

Physiological effects.—The sensations attendant on the passage of an electrical charge, are now so universally known, that a description here would be superfluous. The exaggerated account of their feelings, on the first transmission of a discharge through the bodies of the first experimentalists, was alluded to in the last lecture. It is not, however, easy to explain the cause of the muscular contraction that is experienced. The involuntary action may be produced by the concussion of a material agent passing through the body by an influence on the nervous system, or by a sudden disturbance of the electric equilibrium, and the dull pain at the joints is probably to be traced to the resistance which the electric agent meets with in passing from one bone to another.

It is stated by Mr. Morgan, that if a strong shock is passed through the diaphragm, the sudden contraction of the muscles of respiration, will act so violently on the air of the lungs, as to occasion a loud and involuntary shout; but a small charge occasions in the gravest persons a violent fit of laughter:

persons of great nervous sensibility are affected much more readily than others.

A small charge sent through the spine instantly deprives the person for a moment of all muscular power, and he generally falls to the ground; if the charge be very powerful, instant death is occasioned. Mr. Singer states that a charge passed through the head gave him the sensation of a violent and universal blow, which was followed by transient loss of memory and indistinctness of vision. A small charge sent through the head of a bird, will so far derange the optic nerve, as to produce permanent blindness: and a coated surface of thirty square inches of glass, will exhaust its whole nervous system to such a degree, as to cause immediate death. Animals the most tenacious of life, are destroyed by energetic shocks passed through the body. Van Marum found that eels are irrecoverably deprived of life when a shock is sent through the whole body; when only a part of the body is included in the circuit, the destruction of irritability is confined to that individual part, while the rest retains the power of motion.

It does not yet appear what precise effect, electricity exerts on the functions of the nervous system: the observations of different experimentalists are very variable and contradictory. The Abbé Nollet persuaded himself that perspiration is increased by it, and De Bozes declares he found the pulse to be quickened under the same circumstances; but neither of these results will be allowed to deserve much notice, when the influence which imagination exerts on persons who are the subjects of such experiments, is taken into consideration. That electricity acts as a stimulant, cannot be doubted, and this in point of fact, is all that can be said to be known or established on the subject—it may be remarked that there is here an extensive field of investigation laid open to the speculative medical practitioner.

When the Leyden phial was first discovered, it was imagined that an agent of almost unlimited medical power was raised, and it was applied indiscriminately for the most opposite diseases; the failure consequent on such quackery brought electricity into disrepute, and for a long time it was discarded almost entirely from our hospitals; it is now again more generally employed, and has been found in many cases of great service in palsy, contractions of the limbs, rheumatism, St. Vitus's dance, some kinds of deafness, and impaired vision. It is administered in either of five different ways—1st. Under the form of a gentle stream or aura, from a pointed piece of wood, provided with an insulating handle, and communicating with the prime conductor; by this means it may be directed to parts of great sensibility, as the eye. 2nd. By causing the part to be operated on, to draw sparks from the prime conductor; or, placing the patient on a stool with glass legs, by drawing sparks from him with a metallic ball. 3rd. By the transmission of shocks, which is the most severe and painful, and which requires great caution. 4th. By galvanism. And, 5th, By magneto-electricity; both of which latter methods will be described in another lecture.

It is an established fact, that, animals killed by electricity, undergo rapid putrefaction. The flesh of animals also is found to become tainted much more rapidly by the action of electricity on it. The same has been observed in the bodies of persons killed by lightning. Another remarkable circumstance, is the fact, that blood does not coagulate after death from this cause.

There is no doubt that electricity is very materially concerned both in the economy of animal and vegetable life. In reference to the latter, the information we possess is very small. It is probable that it may have something to do with the rise of sap, from the fact, that electricity always increases the velocity of a fluid moving in a capillary tube. On vegetables, strong shocks have the same effects as on animals, namely, produce death ; a very slight charge is sufficient to kill a balsam. It may further be observed, that vegetables are the most powerful conductors with which we are acquainted. If a blade of grass and a needle are held pointing towards the prime conductor of a machine, while the person holding them recedes, the small luminous point will appear on the apex of the grass long after it has vanished from the apex of the needle.

The following experiment by Pouillet seems to show that a considerable portion of the electricity with which the atmosphere becomes loaded, is derived from the gaseous fluids given out by plants during the processes of vegetation. But it is right also to mention that the experiments instituted by Sir H. Davy, for an account of which, I refer you to the Philosophical Transactions for 1826, p. 398, are rather inconsistent with those of the French electrician.

M. Pouillet arranged in two rows beside each other on a table varnished with gum-lac, twelve glass capsules about eight inches in diameter, coated externally for two inches round the lips with a film of lac varnish; they were filled with vegetable mould, and were made to communicate with each other by metallic wires, which passed from the inside of one, to the inside of the next, going over the edges of the capsules. Thus, the insides of the twelve capsules, and the soil which they contained, formed only a single conducting body. One of these capsules was placed in communication with the upper plate of a condenser, by means of a brass wire; while at the same time the under plate was in communication with the ground.

Things being in this situation, and the weather very dry, a quantity of corn was sown in the soil contained in the capsules, and the effects were watched. The laboratory was carefully shut, and neither ,fire, nor light, nor any electrified body, was introduced into it.

During the two first days the grains swelled, and the plumulæ issued out about the length of a line but did not make their appearance above the surface of the earth. But on the third day the blades appeared above the surface, and began to incline to the window, which was not provided with shutters. The condenser was now charged with positive electricity. Consequently the carbonic acid gas which disengages itself during the germination of the seed, is charged with positive electricity, and is therefore precisely in the same state as the carbonic acid gas formed by combustion. This experiment was several times repeated with success. But the electricity cannot be recognised unless the weather is exceedingly dry, or unless the apartment is artificially dried by introducing substances which have the property of absorbing moisture.

These capsules being insulated, and the air being very dry, and the soil so dry that it is an imperfect conductor, it is evident that the electricity would be retained. Accordingly, when the condenser was brought into a natural state after one observation, and then replaced for experiment, during one second only, it was found to be charged with electricity.

The carbonic acid gas evolved from animals by respiration, no doubt is also charged with positive electricity; although from the moisture with which the expired air is always loaded, and from other circumstances, it would be difficult to establish the fact experimentally.

Lastly, with regard to the physiological effects of this agent, it may be imagined without improbability, that the depression of spirits so generally attendant on damp and gloomy weather, is partly owing to the natural supply of electricity in the body being taken off by the particles of atmospheric moisture; and that the distress experienced by weak and nervous persons, on the approach of a thunder storm, which is often the forerunner of illness, is in some measure, occasioned by the redundancy of the same agent.

Heating Effects.—When electrical shocks are transmitted through thin wires, their temperature is frequently raised sufficiently high to cause their ignition. Nor does it, as was formerly imagined, require a large electrical battery to exhibit this. A single Leyden jar will melt a small piece of flat steel watch pendulum wire. Van Marum fused fifty feet of iron wire, $\frac{1}{140}$th of an inch thick, with a battery consisting of two hundred and fifty-five square feet of surface. We have many instances on record of similar heating effects of atmospheric electricity. In 1708, four persons going from Harwich to Ipswich, in a boat, were killed by a stroke of lightning; the chain and watch in the pocket of one being fused. On another occasion, a stroke fell upon a box of knives and melted some.

The following account of the effects of a flash of lightning, taken from the first volume of the London and Edinburgh Philosophical Magazine, I have thought sufficiently interesting to insert.

"On Friday the 13th of April, 1832, Mr. and Mrs. Thomas F. Boddington, having partaken of some refreshment at Tenbury, placed the servants inside their post chariot, and mounted themselves the barouche seat behind, that they might enjoy the scenery on the road to Bromyard, through the ramifications of the Abberley Hills. It was about half-past three when they left, the sun shining, and the sky serene; but before they had proceeded far, they observed a dark and singular looking cloud to arise, nearly in the direction of their route, and at the end of about three miles and a half, a few drops of rain began to fall; they debated whether they should get inside the carriage, but agreed that the storm (for such it appeared to be) was passing off to the right, and that it would in all probability be only a slight shower, as the cloud in their immediate vicinity, although particularly dark and angry looking, was of very small dimensions. At this time a clap of distant thunder was heard, but no lightning was seen. Mr. Boddington put up an umbrella, but perceiving it was an old one somewhat torn, he gave it to his wife to hold over her bonnet, while he put up another. When in the act of extending the latter, a flash of lightning struck them both senseless, threw the horses on the ground, and cast the post-boy to a considerable distance. The servants inside were untouched, and indeed unconscious of the real nature of the accident. The man says he heard no previous thunder, but that a vivid flash of lightning proceeding as he thought from the side of the road next to which he sat, was accompanied by an instantaneous report like the discharge of a highly loaded blunderbuss, and he concluded that some one had shot the horses. He acknowledges that he was so panic struck, that for a few seconds he sat still; but on recovering from the momentary alarm, he let down the side glass and looked out to see whether his master and mistress were safe. He was shocked to perceive the head of the former hanging over the seat, and apparently lifeless. He immediately jumped from the carriage, and ascended the steps from behind, raised his master's head and found that his clothes were on fire. His mistress was standing up tearing off her bonnet and shawls. Her account of the matter is this: that she neither saw the flash, nor heard the thunder; but her first consciousness was the feeling of suffocation, and that she was pulling off her things to obtain air. She felt however that they had been struck by lightning, and immediately commenced assisting the servants to extinguish the fire, that was still consuming the dress of her husband.

"The passage of the electric fluid as connected with Mrs. Boddington was most distinctly to be traced. It struck the umbrella she had in her hand, which was literally shivered to pieces, both the springs in the handle forced out, the wires that extended the whalebone broken, and the cotton covering rent into a thousand shreds. From the wires of the umbrella, the fluid passed to the wire round her bonnet, the cotton thread that was twisted round that wire, marking the place of entrance over the left eye, by its being burnt off from that spot all round the right side, crossing the back of the head, and down into the neck above the left shoulder; the hair that came in contact with it was also singed; it here made a hole in the handkerchief that was round her throat, and zigzagged along the skin of her neck to the steel busk of her stays, leaving a painful, but not deep wound, and also affecting the hearing of the left ear. It entered the external surface of the busk. This is clearly proved by the brown paper case in which it was enclosed being perforated on the outside, and the *busk itself being fused* for about a quarter of an inch on the upper surface, presenting a blistered appearance. Its passage down the busk could not be traced in any way; there was no mark whatever on the steel, nor was the paper that covered it discoloured or altered in the slightest degree; its exit at the bottom however was as clearly indicated as its entrance at the top; *the steel was fused in the same manner*, and the paper perforated in the same way, but on the opposite side. The busk acquired curious magnetic properties.

"There were marks of burning on the gown and petticoat above the steel; and the inside of the stays and all the garments under the stays were pierced by the passage of the fluid to her thighs, where it made wounds on both: but that on the left, so deep, and so near the femoral artery, that the astonishment is that she escaped with her life; even as it was, the hemorrhage was very great. Every article on which she sat was perforated to the cushion of the seat, the cloth of which was much torn; and it is worthy of observation, that every article the electric fluid passed through, had a singed appearance at the edges, and for a short time a sulphurous smell. No ignition of any of the combustible articles took place; nor did the lady's wounds present the appearance of burns. The cushion of the barouche seat was stuffed with horse hair, through which the stream must have passed, though no sign to indicate its passage was visible; the cloth edge of the cushion however, immediately behind where Mrs. Boddington sat, was torn outwards, and the leather that covered the iron forced off in the same spot; clearly marking its egress at this place.

"As this same iron also received the charge that struck Mr. Boddington, I shall now state the effects of the lightning on him, before I trace its further progress.

"When first discovered, he was insensible, in which state he remained for about ten minutes, when he revived sufficiently to enquire where he was, but relates that he was perfectly unconscious of what had occurred; that he felt his eyesight affected, and a pain all over him, but that he knew not from what cause these sensations arose.

"The umbrella in this case was also the conductor. The main force of the shock appears to have passed down the handle to his left arm, though a portion of it made a hole through the brim of his hat, and burnt off all the hair that was below it, together with his eyelashes and eyebrows: the fragments of the burnt parts falling into his eyes, deprived him of sight for two or three days, but his eyes were not otherwise injured; his left hand was shattered, *his gold shirt buttons fused,* and his clothes torn in a most extraordinary manner, and a deep wound was inflicted in his wrist. His arm was laid bare to the elbow, which is presumed to have been at the moment, very near the left waistcoat pocket, in which there was a knife; this also was forced from its situation, and found upon the ground; a severe wound was made on his body, and every part of his dress torn away as if by gunpowder. From the knife it passed to the iron of the seat, wounding his back and setting fire to his clothes in its passage. Another portion descended to the right arm,-which had hold of the lower part of the stick of the umbrella, was attracted by the sleeve button, where it made a wound, but slight as compared with that on the left, passed down the arm to a gold pencil case in the right waistcoat pocket. His great coat was torn to pieces, and the coat immediately above the waistcoat pocket much rent; but the waistcoat itself was merely perforated on the external part where the discharge entered by a hole about the size of a pea, and on the inside by a similar hole at the other extremity of the pencil case, where it passed out, setting fire to his trowsers and drawers, and inflicting a deep wound round his back, *the whole of which was literally flayed.*

"The whole shock was now collected in the iron which formed the back of the barouche seat; it was broken in two, immediately opposite the spring, and the ends of the fractured parts bent forward so as nearly to touch it. By this conveyance it is supposed to have diffused itself over the whole of the under carriage, and to have passed to the earth by the tires of the wheels, four holes being made in the road at the points they touched at the moment of the shock; though the carriage was not standing in them at the time it stopped. The horse the postillion rode was *found to be dead,* the other was not hurt, but evidently panic struck. He rose as soon as the harness was cleared from him, in a profuse sweat and trembling. On inspecting the dead horse no wound was found, nor any apparent cause for his death; but when he was skinned, *the flesh down the spine for about three inches in width was quite black and putrid.* The post-boy was thrown off some yards, but perfectly unhurt.

"The collateral facts must now be mentioned. The landlord of the inn at Tenbury, saw the flash of lightning that must have caused the accident; he observed, that he had never before seen so singular a flash, as it appeared to divide into four parts when it came within about thirty yards of the earth. It should seem therefore that they were not struck by a single discharge of electric matter, but were enveloped in a mass of electricity; and this is the more probable, from the traces of the different strokes being so distinct, and yet taking such opposite directions. The fluid seems to have pervaded the whole atmosphere, as many things were magnetised* that were not in the line of any of the tracks that could be traced. For instance Mr. Boddington's watch was in his fob, and quite out of the line described by either of the shocks that passed over him. After the accident, it was found necessary to send it to a watchmaker, who, on taking it to pieces, found the steel parts, particularly the balance wheel to be highly magnetised. Two pair of scissors also, that were in Mrs. Boddington's work box, were found accidently, two months after the accident to be magnetic."

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* By passing a strong charge from a Leyden phial in a particular manner through a common sewing needle, it will be rendered permanently magnetic.

The electric agent is not the same thing as the element of fire, as Cavallo has shown; for the metals do not exhibit the same degree of fusibility, as they do in chemical furnaces, but seem to be affected in a manner proportionate to the degree of resistance which they offer. Combustible liquids may be fired by a Leyden phial. Wrap some cotton round one of the knobs of the discharging rod, and having dipped it in sulphuric ether, complete the electrical circuit by bringing the covered ball in contact with the knob of a charged jar; and the other end in contact with the exterior coating, the ether will be immediately inflamed. Or let a person stand on the insulating stool, and hold in one hand a chain, connected with the prime conductor; and in the other a metallic vessel containing ether, or warm spirits of wine; either of these combustibles may then be ignited by another person merely touching them with his finger.

There is a singular fact connected with the inflammation of gunpowder by electricity. Unless it is finely powdered and rammed into a tube or quill, and the discharge of a large jar passed through it by points of iron wire, it will generally be thrown about, but not exploded. But if the current is *retarded*, by being made to pass through an imperfect conductor, such as water,* the gunpowder under such circumstances will always be ignited, as will appear from the following experiment:—

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* NOTE.—There is a visible difference in the appearance of the spark from a Leyden phial, in passing between perfect and imperfect conductors. In the latter case, as when it is made to pass through a length of wet string placed in the circuit, the spark is yellowish, flamy, and of sensibly longer duration than if the water had not been interposed; and is accompanied by little or no noise.

Place some loose gunpowder in an ivory mortar, and send the explosion from a large jar through it, in the usual manner, by means of interrupted wires; the powder will be dispersed but not ignited.

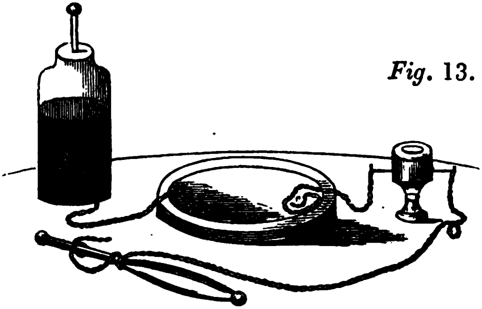

Fig. 13.

Now repeat the experiment, placing a basin of water in the circuit, (as in Fig. 13,) so that it may be interrupted by ten or twelve inches of that fluid; the spark under such circumstances will invariably fire the powder: or the circuit may be interrupted by a few inches of pack-thread, well soaked in water, and the same effect will ensue. There does not seem at present to be any way of accounting for this.

Mechanical Effects.—The increase of temperature resulting from a discharge through an imperfect conductor, may have something to do with mechanical concussion: expansion of the substances operated on frequently occurs. This may be shown to be the case both with solids and fluids, by the following experiments:—Let a powerful charge be passed over a quantity of dough or pipe clay, an indentation will be formed, marking the passage of the current; or, pass a strong shock under a pane of glass kept down by a weight, it will be shivered to pieces. Again, a comparatively small charge will perforate half a quire of writing paper, or a thick card, in either of which a strong sulphurous smell will for a short time be perceived. If a strong shock is passed through a tube of water, the tube is invariably broken. And if two blunt wires are inserted in a piece of wood about half an inch long, and a quarter of an inch thick, so that the ends of the wires shall be about an eighth of an inch from each other, a powerful shock transmitted through the wires will generally split the wood.

These facts show that electricity is capable of producing violent mechanical effects upon bad conductors, and upon good ones, that are not of sufficient size to afford a ready passage.

Certain crystallized minerals, among the most remarkable of which is the Tourmaline, possess the property of acquiring electricity, by simply being heated and cooled. If a large piece of this mineral is heated from 100° to 212° Fahr., its opposite sides become charged with opposite electricities, as may be proved by the electroscope; in very large specimens flashes of light are observed. The topaz, axinite, mesotype, and some others, among minerals; and the oxide of zinc (calamine), and the oxide of titanium (sphene), among metals, are possessed of similar properties. Many substances also in passing from the liquid to the solid state, become electrified, such as sulphur, gum-lac, and in fact, all resins. The electricity in these cases is usually disguised; it requires precaution to develop it. Thus on melting sulphur in an iron ladle, no signs of electricity are exhibited; the negative of the one, being exactly counterbalanced by the positive of the other; but if the same substance be melted in a wine glass, on removing it when cold, it is always found negatively charged, and the glass positively: but when it is replaced in the glass all indications of excitement disappear. When water is evaporated from the cap of an electrometer, it always leaves the instrument in a negative state, the steam carrying off positive electricity. But it appears to be essential that the vessel from which the water is evaporated should be metallic, and that it should be undergoing chemical action, that is, that during the vaporization of the water, a portion of it should be decomposed, and that oxygen should unite with the metal. Water evaporated from dishes of platina or gold, does not evince any signs of electricity.—*(See M. De la Rive's experiments. Lecture* 4.*)*

The following beautiful experiment devised by Lichtenburg, will serve to prove, that when certain substances are rubbed together, they acquire opposite electricities. Charge a Leyden phial positively in the usual manner, then take it in one hand, and make the knob rub against the surface of a thin plate of glass covered with lac varnish; the parts of the plate touched by the knob, will have acquired positive electricity, and the parts opposite on the under surface of the glass, will have acquired negative electricity. If the glass plate be now suspended, insulated in the air, and a *mixture of sulphur and minium powder* previously triturated together in a mortar be blown on it, the minium alone will adhere to the parts of the plate that have been electrified positively; if the same mixture be blown on the other side, the sulphur alone will adhere. Thus we shall have the same lines traced on the two sides of the glass plate; but with different coloured powders. The positive side will be covered with the red powder of minium; and the negative side with the yellow powder of sulphur. The reason is, that when sulphur and minium are triturated together, sulphur acquires positive, and minium negative electricity.

Chemical Effects.—This influence of electricity is most conspicuously exerted in that modification of the agent, known by the name of galvanism. In the second lecture on that subject, therefore, it will be more fully entered into: at present, I shall merely adduce a few instances illustrative of the chemical effects of electricity, in the form in which it has hitherto been considered.

Dr. Priestley was the first person who investigated the chemical effects of ordinary electricity, by passing a succession of sparks through a small quantity of water, tinged blue by litmus: the liquid in a short time, acquired a red tinge, while the air, confined in the tube, suffered evident diminution, an acid had been formed by the chemical union of the elements of atmospheric air, viz., nitrogen and oxygen. It was Mr. Cavendish, however, that first explained this experiment of Priestley. His experiments are detailed in the Philosophical Transactions for 1784.

When a succession of discharges are sent through water, a decomposition of that fluid takes place; the elements of which assume the gaseous form of oxygen and hydrogen. This fact was discovered in 1789, by Messrs. Dieman, Paetz, and Van Troostwyck, associated with Mr. Cuthbertson. For this experiment, they employed a glass tube, a foot long, and one eighth of an inch in diameter; through one end of which, a gold wire was inserted, projecting about an inch and a half within the tube; that end was then hermetically sealed. Another wire was introduced at the other end of the tube which was left open, and passed upwards, so that its extremity came to a distance of five-eighths of an inch from the end of the first wire. The tube was then filled with distilled water, from which the air had been extracted by an air pump, and inverted in a vessel containing mercury. A little common air was let into the top of the tube, in order to prevent its being broken by the discharge. Electrical shocks were then passed between the two ends of the wires through the water in the tube, by means of a Leyden jar, which had a square foot of coated surface. This jar was charged by a very powerful double plate machine, which caused it to discharge twenty-five times in fifteen revolutions; at each explosion, bubbles of gas rose to the top of the tube; and when sufficient water had been displaced, to lay bare the wires, the next shock kindled the gases and caused their reunion; thus decomposition and recomposition were effected by the same agent. In the latter case however, it may be supposed to have acted mechanically, or by the heat evolved in its passage through a badly conducting æriform fluid.

In 1801, Dr. Wollaston published in the Philosophical Transactions, a description of a method of analyzing water by the transmission of *sparks* instead of shocks. The following is extracted from his paper on the subject:—

"It has been thought necessary for the decomposition of water, to employ powerful machines and large jars; but when I considered that the decomposition must depend upon duly proportioning the strength of the charge of electricity, to the quantity of water, and that the quantity exposed to its action at the surface of communication, depends on the extent of that surface, I hoped, that by reducing the surface of communication, the decomposition of water might be effected by smaller machines, and with a less powerful excitation than have hitherto been used for that purpose.

"Having procured a small wire of fine gold, and given to it as fine a point as I could, I inserted it into a capillary glass tube; and after heating the tube so as to make it adhere to the point, and cover it at every part; I gradually ground it down, till with a pocket lens I could discern that the point of gold was exposed.

"The success of this method exceeded my expectation. I coated several wires in the same manner, and found that when sparks from the conductors before mentioned, were made to pass through water, by means of a point so guarded, a spark passing to the distance of one-eighth of an inch would decompose water, when the point exposed did not exceed one-seven hundredth of an inch in diameter. With another point which I estimated at one-fifteen thousandth, a succession of sparks one-twentieth of an inch in length afforded a current of small bubbles of air."

In these experiments the gases were given off from both poles. Dr. Faraday has, however, with his usual ability devised a simple plan for evolving the gases as in voltaic arrangements; that is, oxygen from the one, and hydrogen from the other. It will not be out of place to insert the Professor's description of his apparatus.

"Upon a glass plate, placed over, but raised above a piece of white paper, so that shadows may not interfere, put two small slips of tin foil, connect one of these by an insulated wire with a machine, and the other with the discharging train or negative conductor.

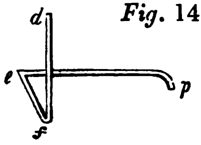

Fig. 14.

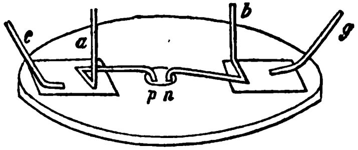

Fig. 15.

"Provide two pieces of fine platinum wire bent as in the *Fig.* 14, so that the part *d f* shall be nearly upright, while the whole is resting on the three bearing points *p e f;* place these as in *Fig.* 15; the points *p n* become then the decomposing poles. Place a large drop of muriatic acid, rendered blue by sulphate of indigo, so that *p* and *n* may be immersed in it at opposite sides; then send a current of electricity through it from a good machine, and chlorine, shown by its bleaching effects, will be evolved at *p*." (This experiment is the counterpart of those on voltaic electricity, that will be described in another lecture.) "Place a drop of solution of iodide of potassium mixed with starch, between the poles, and the current will evolve iodine at *p*. Put a drop of solution of copper between the poles, and the current will then cause the precipitation of metallic copper at *n*."

In these experiments the direct passage of sparks must be carefully avoided. If sparks are passed over moistened litmus-paper, it is reddened; and if over paper moistened with iodide of potassium, iodine is evolved. But these effects must carefully be distinguished from those due to true electro-chemical powers, or *electrolytic action*, and must be carefully avoided, when the latter are sought for. The effect just mentioned, is due to the formation of *nitric acid*, by the combination of the oxygen and nitrogen of the air; the acid so formed, though very small in quantity, is in a high state of concentration, and therefore reddens the litmus-paper, and decomposes the iodide.

It must have been often noticed by persons in the habit of using an electrical machine, that its action is accompanied by the emission of a peculiar odour, particularly when it passes from the prime conductor by a pointed wire. It is rendered probable from the above experiments of Faraday that this odour is derived from the production of nitric acid, by the action of electricity on the air of the atmosphere. By moistening a very small slip of litmus-paper in a solution of caustic potash, and then passing a succession of sparks over its length in the air, Dr. Faraday gradually neutralized the acid, and ultimately rendered the paper red; and on drying, he found that *nitrate of potassa* had resulted from the operation, and that the paper had become touch paper. These experiments furnish a ready means of illustrating Cavendish's experiment of forming nitric acid from atmospheric air.

The air circumscribing the globe, and which we breathe, is extremely uniform in all parts of the world, and at all heights above its surface.—Its essential component parts are generally considered to be

	By measure.	By weight.
Oxygen........	21........	23
Nitrogen	79........	77
	100	100

These gases are merely in a state of mechanical mixture, and by no means, as some have imagined chemically combined; but when they are acted on by electricity, a more intimate union is established between them in other proportions; seventy-four parts of oxygen then combine *chemically* with twenty-six of nitrogen, and nitric acid in a high state of concentration is the result. Thus the air which we inhale, and which is absolutely essential to our very existence, is composed of precisely the same ingredients as, and is convertible into, the most highly corrosive acid with which chemists are acquainted; and this by the action of a current of ordinary electricity.

Atmospheric Electricity.—The atmosphere when clear is always positively electric. The electricity is stronger in winter than in summer, during the day than in the night. The intensity increases for two or three hours from the time of sun rise, comes to a maximum between seven and eight, then decreases towards the middle of the day; arrives at its minimum between one and two; and again augments as the sun declines, till about sun-set; after which it diminishes, and continues feeble during the night.

It is called into action on a grand and sublime scale, in the production of the thunder storm. It is by no means ascertained whence this enormous supply of electricity is obtained;* but it is probably connected with some peculiar power in masses of ærial vapour to receive and retain electrical charges; but this does not admit of imitation.

The analogy between the electric spark and lightning, was noticed at an early period of electrical science; but it is to the sagacity and courage of the celebrated Franklin, that we are indebted for a demonstration of this analogy. In the Encyclopædia Britannica we find the following account of this remarkable discovery:—

"Franklin begins by cautioning his readers not to be staggered at the great difference in point of *degree* between the electric fluid and lightning. It is no wonder that the effects of one should so far exceed those of the other; for if two gun-barrels will at the distance of two inches strike and make a report when electrified, at how great a distance must ten thousand acres of electric cloud strike and give its fire, and how loud must be the crash. He then adds, that flashes of lightning are generally crooked and waving; and so is a long electric spark. That lightning, like common electricity, strikes the highest and most pointed objects in its way; that it takes the readiest and best conductors, that it sets fire to inflammable bodies, rends others to pieces, and melts metal. Lightning, he adds, has often been known to strike people blind; and the same happened to a pigeon that had received a violent electrical shock.

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* NOTE.—Pouillet declares that no electricity is evolved by evaporation, unless some chemical combination takes place at the same time; but that it is abundantly given out during combustion. The burning body giving out negative, and the oxygen, positive electricity. In like manner the carbonic acid emitted by vegetables is charged with negative electricity, and the oxygen (probably) with positive. Are these two sources sufficient to account or the vast quantity of electricity so often accumulated in the clouds?—*See Ann. de Chim. et de Phys.* xxxv. 401.

"Reasoning on these facts, and having observed that pointed conductors appear to attract electricity, he conceived that pointed rods of iron fixed in the air might draw from the clouds their electric matter, without noise or danger; he says, the electric fluid is attracted by points; we do not know whether this property exists in lightning: but since they agree in all particulars, in which we can already compare them, it is not improbable that they agree in this also. *Let the experiment be made.*

"In the year 1752, while waiting for the erection of a spire, in the city of Philadelphia, not imagining that a pointed rod elevated to a considerable height, would do as well, it occurred to him that by means of a common kite, he might have ready access to the higher regions of the atmosphere. Preparing, therefore, a large silk handkerchief, and two cross sticks to extend it on, he took the opportunity of the first approaching thunder-storm, and went into a field where there was a shed proper for his purpose. But dreading the ridicule which he feared might attend an unsuccessful attempt, he communicated his intention to no one but his son, who assisted him in flying the kite. The kite was raised; a considerable time passed without appearance of success, and a promising cloud passed over without effect, when, just as he was beginning to despair, he observed some loose threads upon the string of the kite begin to diverge and stand erect: on this he fastened a key to the string, and on presenting his knuckle to it, was gratified by the first electric spark, that had thus been drawn from the clouds; others succeeded, and when the string had become wet by the falling rain, a copious stream of electric fire passed from the conductor to his hand; a large quantity was collected, and in the shed he repeated with it all the experiments usually performed by a machine; and that no opportunity of making such experiments might be lost, he attached a chime of bells to the electric rod, which he had insulated, in order to draw the lightning of the clouds into the shed, and these by ringing gave notice of the electrical state of the apparatus."

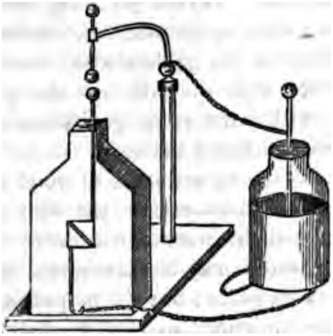
It is easy to conceive the feelings with which Franklin thus contemplated the successful result of his bold experiment. We are told that when he saw the fibres of the string diverge, and the spark pass, he uttered a deep sigh, and wished that the moment was his last. He felt that his name would be immortalized by the discovery.

These interesting experiments were of course repeated, in almost every civilized country, with variable success. In France a grand result was obtained by M de Romas; he constructed a kite seven feet high, which he raised to a height of five hundred and fifty feet, by a string having a fine wire interwoven through its whole length. On the twenty-sixth of August, 1756, sparks were darted from the string of this kite an inch in diameter and ten feet long.

In the prosecution of these and similar experiments, we only find one instance attended with fatal results. Professor Richman, of Petersburgh, had constructed an apparatus for experiments on atmospheric electricity, entirely insulated, and not provided with an arrangement for discharging itself, when too strongly electrified. On the sixth of August, 1763, he was struck dead by a flash of lightning from the insulated rod, having inadvertently approached too close to it: a red spot was found on his forehead, his shoe was burst open, and a part of his waistcoat singed; the door of the room was split, and torn off its hinges.

Among the important practical results to which the discovery of the identity of lightning and electricity led, was the application of conductors to buildings and ships, by which their safety in a thunder-storm is almost insured. In the choice of a conductor, preference should be given to copper, and it is well to divide the extremity into three or four points; the rod should be secured to the side of the building in its descent, and penetrate the ground sufficiently deep to be in close contact with a moist stratum of soil. The following experiment will amusingly illustrate the use of a continuous conductor.

Fig. 16.



Provide a board about three quarters of an inch thick, and shaped like the gable end of a house; fix this board perpendicularly upon another board, upon which a glass pillar is also to be fixed, in a hole about eight inches distant from the gable shaped board; a small hole about a quarter of an inch deep and nearly an inch wide, is to be made in the latter, to be filled with a square piece of wood nearly of the same dimensions. It should be *nearly* of the same dimensions, because it must go so easily into the hole, that it may drop off by the least shaking of the instrument. A brass wire is fastened diagonally to this square piece of wood, and another of the same dimensions, terminated by a brass ball, is fastened on the gable shaped board, both above and below the hole. From the upper extremity of the glass pillar, a crooked wire proceeds, terminated also by a brass ball, and sufficiently long to reach immediately over the ball on the wire of the board. The glass pillar is to be loosely fixed in the bottom board, so that it may easily move round its axis. It is evident that with this arrangement, a shock from a Leyden jar, may easily be sent over the square hole, by connecting the exterior coating, with the wire in the gable shaped board, below it, and the interior with the wire on the glass pillar, which comes within the striking distance of the wire in the gable shaped board below it.

Suppose, now, the square piece of wood is placed in the hole, in such a manner that the wire attached to it diagonally, shall be in contact with the wires above and below it, a shock may be transmitted without any disturbance taking place; but if it be put into the hole in an opposite direction, so that the shock from the jar shall be obliged to pass over it altogether, in the form of a spark, in its passage from wire to wire, the concussion it will occasion, will throw the square piece of wood to a considerable distance from the apparatus. Here the square wood may be supposed to represent a window, and the wire a continuous or a broken conductor, passing by the side of it, and the violent effects produced by the minute quantity of electricity accumulated in a Leyden jar, may be considered as a humble imitation of the effects of a stroke of lightning. When the passage is uninterrupted, the electricity passes quietly down, but when impeded, it produces the most violent effects.

To exemplify the method of defending ships, a small model may be made, with a glass tube for the mast. In this tube two wires are to be inserted, through its opposite ends, until within half an inch of each other. The tube is then to be filled with water, and the ends stopped. Connect the lower wire with a small metal thread, tied to the stern. The upper wire is to be surmounted by a brass ball. A moveable conductor may be formed of a thin copper wire, placed parallel with, and rising above the mast. This wire is to be connected at the bottom with the metal thread. If a powerful charge be passed along the mast when the conductor is attached, no effect is produced; but if the conductor be removed, the mast is shattered to pieces.

When a building is struck by lightning, the charge is generally determined towards the chimney, owing to its height, and to the conducting power of the carbon deposited in it; for it is demonstrated, experimentally, that the electric fluid will pass with facility to a considerable distance over a surface of carbon.

Few and simple are the directions to be given, as to the best means of safety during a thunder-storm. If out of doors, trees should be avoided; and if, from the rapidity with which the explosion follows the flash, it should be evident that the electric clouds are near at hand, a recumbent posture on the ground is the most secure.* It is seldom dangerous to take shelter under sheds, carts, or low buildings, or under the arch of a bridge; the distance of twenty or thirty feet from tall trees or houses, is rather an eligible situation, for should a discharge take place, these elevated bodies are most likely to receive it, and less prominent bodies in the neighbourhood are more likely to escape. It is right also to avoid *water*, for it is a good conductor, and the height of a human being near a stream is likely to determine the direction of a discharge. Within doors we are tolerably safe in the middle of a carpeted room, or when standing on a doubled hearth-rug. The chimney should be avoided, for reasons above stated. Upon the same principles, gilt mouldings, bell-wires, &c., are in danger of being struck. In bed we are tolerably safe, blankets and feathers

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NOTE.—Sound travels at the rate of 1142 feet in a second. The velocity of light is so great, that its motion through any ordinary distance, need not be taken into consideration: consequently the interval in seconds that elapses between the flash and the report, multiplied by 1142, will give the observer, in feet, the distance of the explosion. Suppose the flash of lightening to be seen, and we count six seconds before we hear the thunder:—1142 × 6=6852ft., the distance from us, at which the explosion has taken place. But though one explosion may take place at this distance, the very next discharge may occur very near us; for thunder clouds frequently extend over a considerable extent of country, and two, or even a greater number of flashes are sometimes seen in distant points in the atmosphere nearly at the same time.—*Leithead's electricity.*

being bad conductors, and we are, consequently, to a certain extent insulated.

The appearance of the heavens during a thunder storm, is thus described by Dr. Thomson.

"A low, dense cloud begins to form in a part of the atmosphere, that was previously clear. This cloud increases fast, but only from its upper part, and spreads into an arched form, appearing like a large heap of cotton wool. Its under surface is level, as if it rested on a smooth plane. The wind is hushed, and every thing appears preternaturally calm and still.

"Numberless small ragged clouds, like teazled flakes of cotton, soon begin to make their appearance, moving about in various directions, and perpetually changing their irregular surface, appearing to increase by gradual accumulation. As they move about, they approach each other, and appear to stretch out their ragged arms towards each other. They do not often come in contact, but after approaching very near each other, they evidently recede, either in whole, or by bending away their ragged arms.

"During this confused motion, the whole mass of small clouds approaches the great one above it: and when near it, the clouds of the lower mass frequently coalesce with each other, before they coalesce with the upper cloud. But as frequently the upper cloud coalesces without them. Its lower surface from being level and smooth, now becomes ragged, and its tatters stretch down towards the others, and long arms are extended towards the ground. The heavens now darken apace, and the whole mass sinks down. Wind rises, and frequently shifts in squalls. Small clouds move swiftly in various directions. Lightning darts from cloud to cloud. A spark is sometimes seen coexistent through a vast horizontal extent of a zigzag shape, and of different brilliancy in different parts. Lightning strikes between the clouds and the earth. Frequently in two places at once, a very heavy rain falls; the cloud is dissipated, or it rises high and becomes light and thin.

"These electrical discharges obviously dissipate the electricity—the cloud condenses into water, and occasions the sudden and heavy rain which always terminates a thunder storm. The previous motions of the clouds, which act like electrometers, indicate the electrical state of different parts of the atmosphere."

A great difference will be observed in the appearance of the flashes of lightning during a thunder storm. The scene is sometimes rendered awfully magnificent by their brilliancy, frequency, and extent; darting sometimes in broad and well defined lines from cloud to cloud, and sometimes shooting towards the earth; they then become zigzag and irregular, or appear as a large and rapidly moving ball of fire, an appearance usually designated by the ignorant a *thunder bolt,* and erroneously supposed to be attended by the fall of a solid body. The report of the thunder is also modified according to the nature of the country, the extent of the air through which it passes, and the position of the observer. Sometimes it sounds like the sudden emptying of a large cart-load of stones; sometimes like the firing of a volley of musketry; in these cases it usually follows the lightning immediately, and is near at hand; when more distant, it rumbles and reverberates, at first, with a loud report, gradually dying away and returning at intervals, or roaring like the discharge of heavy artillery. In accounting for these phenomena, it must be remembered that the passage of electricity is infinitely rapid. A discharge through a circuit of many miles has been experimentally proved to be instantaneous; the motion of light is similarly rapid,* and hence the flash appears momentary, however great the distance through which it passes. But

NOTE.—Light is about eight minutes thirteen seconds in passing from the sun to the earth, so that it may be considered as moving at the rate of one hundred and ninety-two thousand miles in a second; and in the language of Herschel, (*Discourse on the study of Natural Philosophy,*) it performs the tour of the world in about the same time that it requires to wink with our eye-lids, and in much less, than a swift runner occupies in taking a single stride.

The sun is ninety-five millions of miles from the earth, and almost a million times larger; the sun being eight hundred and eighty-two thousand miles in diameter, and the earth eight thousand four hundred. Yet its magnitude, as viewed from the earth, scarcely exceeds that of the moon, which is not more than one-fourth the diameter of our globe, being two thousand one hundred and sixty miles in diameter. Yet such is the velocity of light, that a flash of it from the sun, would be seen in little more than eight minutes after its emission; whereas, the sound evolved at the same time, (supposing a medium like air capable of conveying sound between the sun and the earth,) would not reach us in less than fourteen years and thirty-seven days; and a cannon ball proceeding with its greatest speed in not less than twenty years.

The velocity of electricity is so great, that the most rapid motion that can be produced by art, appears to be actual rest when compared with it. A wheel revolving with celerity sufficient to render its spokes invisible; when illuminated by a flash of lightning is seen for an instant with all its spokes distinct, as if it were in a state of absolute repose: because, however rapid the rotation may be, the light has come and already ceased, before the wheel has had time to turn through a sensible space. This beautiful experiment is due to Professor Wheatstone, as well as the following variation, which is not less striking:—Since a sun-beam consists of a mixture of blue, yellow, and red light; if a circular piece of pasteboard be divided into three sectors, one of which is painted blue, another sound is infinitely slower in its progress, moving at the rate of about twelve miles in a minute. Now, sup-

yellow, and a third red, it will appear to be white when revolving quickly, because of the rapidity with which the impression of the colours succeed each other on the retina. But the instant it is illuminated by an electric spark, it seems to stand still, and each colour is as distinct, as if it were at rest. This transcendent speed of the electric fluid has been ingeniously measured by Professor Wheatstone; and although his experiments are not far enough advanced, to enable him to state its absolute celerity, he has ascertained that it much surpasses the velocity of light.

An insulated copper wire, half a mile long, is so disposed that its centre and two extremities terminate in the horizontal diameter of a small disc or circular plate of metal, fixed on the wall of a darkened room. When an electric spark is sent through the wire, it is seen at the three points, apparently at the same instant. At the distance of about ten feet, a small revolving mirror is placed, so as to reflect these three sparks during its revolution. From the extreme velocity of the electricity, it is clear, that if the three sparks are simultaneous, they will be reflected, and will vanish before the mirror has sensibly changed its position, however rapid its rotation may be, and they will be seen in a straight line. But if the three sparks are not simultaneously transmitted to the disc, if one, for example, is later than the other two, the mirror will have time to revolve through an indefinitely small arc, in the interval between the reflection of the two sparks, and the single one. However, the only indication of this small motion of the mirror, will be, that the single spark will not be reflected in the same straight line with the other two, but a little above or below it; for the reflection of all three will still be apparently simultaneous, the time intervening being much too short to be appreciated.

Since the distance of the revolving mirror from the disc, and the number of revolutions which it makes in a second, are known, the deviation of the reflection of the single spark, from the reflection of the other two, can be computed, and consequently the time elapsed between their consecutive reflections can be ascertained. And as the length of that part of the wire through which the electricity has passed, is given, its velocity may be found.

posing the lightning to pass through a space of some miles, the explosion will be first heard from the point of the air agitated, nearest the spectator: it will gradually come from the more distant parts of the course of the electricity; and last of all will be heard from the remote extremity. And the different degrees of the agitation of the air, and likewise the difference of the distance, will account for the different intensities of the sound, and the apparent reverberation and charges.

Thunder only takes place when the different strata of air are in different electrical states: the clouds interposed between these strata, are also electrical, and owe, (according to Dr. Thomson,) their vesicular nature to that electricity. They are also conductors. The discharges usually take place between two strata of air; very rarely between the air and the earth; and sometimes without noise, in which case, the flashes are very bright; but they are single, passing visibly from one cloud to another, and confined usually to a single quarter of the heavens. When the discharge is accompanied by thunder, a number of simultaneous and different coloured flashes may generally be observed stretching to an extent of several miles. These seem

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Since the number of pulses in a second requisite to produce a musical note of any pitch is known, the number of revolutions accomplished by the mirror in a given time, is determined from the musical note produced by a tooth or peg in its axis of rotation striking against a card; or from the notes of a siren attached to the axis. It was thus, that Mr. Wheatstone found the velocity of the mirror to be such, that an angular deviation of twenty-five degrees in the appearance of the two sparks, would indicate an interval not exceeding the millioneth of a second.—*(Mrs. Somerville's Connexion of the Physical Sciences.)*

to be occasioned by a number of successive discharges from one cloud to another, the intermediate clouds serving as intermediate conductors, or stepping stones as it were for the electrical fluid. It is these discharges which occasion the rattling noise. Though they are all made at the same time, yet, as their distances are different, they only reach our ear in succession, and thus occasion the lengthened rumbling noise, so different from the snap which accompanies the discharge of a Leyden jar.

Sometimes the equilibrium of the clouds is restored by a single flash of lightning: at other times, the accumulation is so immense, and the neighbouring strata of air so strongly charged, that the flashes continue for hours before they terminate in a storm of rain.

A person may be killed by lightning, although the explosion takes place twenty miles off, by what is called the back stroke. Suppose that the two extremities of a cloud highly charged hang down to the earth, they will repel the electricity from the earth's surface, if it be of the same kind as their own, and will attract the other kind: if a discharge should suddenly take place at one end of the cloud, the equilibrium will instantly be restored by a flash at that point of the earth which is under the other. Though this back stroke is often sufficiently powerful to destroy life, it is never so terrible in its effects as the direct shock.

Waterspouts, and volcanic eruptions in the sea are generally attended by thunder and lightning, and may be classed among electrical phenomena. In June 1811, Captain Tillard observed off the Island of St. Michael, one of these marine volcanoes, of which he has given the following description in the Philosophical Transactions. "Imagine," says he, "an immense body of smoke rising from the sea, the surface of which was marked by the silver rippling of the waves occasioned by the slight and steady breezes incidental to those climates in summer. In a quiescent state, it had the appearance of a circular cloud, revolving on the water like a horizontal wheel, in various and irregular involutions, expanding itself gradually on the lee side, when suddenly a column of the blackest cinders, ashes, and stones, would shoot up in the form of a spire, rapidly succeeded by others, each acquiring greater velocity, and breaking into various branches resembling a group of pines; these again forming themselves into festoons of white feathery smoke. During these bursts, the most vivid flashes of lightning continually issued from the densest part of the volcano, and the columns rolled off in large masses of fleecy clouds, gradually expanding themselves before the wind, in a direction nearly horizontal, and drawing up a quantity of waterspouts, which formed a striking addition to the scene. In less than an hour, a peak was visible, and in three hours from the time of our arrival, the volcano, then being four hours old, a crater was formed twenty feet high, and from four to five hundred feet in diameter. The eruptions were attended by a noise like the firing of cannon and musketry mixed; as also with shocks of earthquakes, sufficient to throw down a large part of the cliff on which we stood. I afterwards visited the volcanic island: it was eighty yards high, its crater upon the level of the sea was full of boiling water; it was about a *mile* in circumference, and composed of porous cinders, and masses of stone."

The aurora borealis is unquestionably connected with electricity in some way, though it does not appear at present in what precise manner: its appearance may be imitated with great exactness by artificial electricity; for if a tube be partially exhausted of air, and a stream of electricity sent through it, the same variety of colour and intensity, the same undulating motions, and occasional corruscations, and the same inequality in the luminous appearance, are exhibited as in the aurora, and when the rarefraction is considerable, (Mr. Singer observes) various parts of the stream assume that peculiar glowing colour, which occasionly appears in the atmosphere, and which is regarded by the uninformed observer, with astonishment and fear.

The aurora borealis is seldom seen in perfection in this country, and of late years has rarely been noticed at all. But Captain Parry in his second voyage for the discovery of a north west passage, had abundant opportunities of observing it in the greatest splendour. That highly distinguished philosopher and chemist, Dr. Dalton, has also furnished us with an account of an aurora, noticed by him, on the 15th of October, 1792. I shall take the liberty of inserting an extract from it, and also an abstract of Captain Parry's description of an aurora observed by him on the 11th of December, 1821.

" Attention was first excited" says Mr. Dalton, " by a remarkably red appearance of the clouds to the south, which afforded sufficient light to read by, at eight o'clock in the evening, though there was no moon nor light in the north. From half-past nine to ten there was a large, luminous, horizontal arch to the southward, and several faint concentric arches northward. It was particularly noticed that all the arches, seemed exactly bisected by the plane of the magnetic meridian. At half-past ten o'clock streamers appeared, very low in the south east, running to and fro from west to east; they increased in number, and began to approach the zenith apparently with an accelerated velocity; when all on a sudden the whole hemisphere was covered with them, and exhibited such an appearance as surpasses all description. The intensity of the light, the prodigious number and volatility of the beams, the grand intermixture of all the prismatic colours in their utmost splendour, variegating the glowing canopy with the most luxuriant and enchanting scenery, afforded an awful, but at the same time, the most pleasing and sublime spectacle in nature. Every one gazed with astonishment, but the uncommon grandeur of the scene only lasted *one minute;* the variety of colours disappeared, and the beams lost their lateral motion, and were converted into the flashing radiations.

"Notwithstanding the suddenness of the effulgence, at the breaking out of the aurora, there was a remarkable regularity in the manner. Apparently a ball of fire ran along from east to west, with a velocity so great as to be barely distinguishable from one continued train, which kindled up the several rows of beams one after another. These rows were situated before each other with the exactest order, so that the base of each row formed a circle, crossing the magnetic meridian at right angles; and the several circles rose one above another, so that those near the zenith appeared more distant from each other than those near the horizon, a certain indication that the real distances of the rows were nearly the same. The aurora continued for several hours. There were many meteors, falling stars (as they are commonly called) seen at the same time; but they appeared to be below and unconnected with the aurora."—*(Dalton's Meteorological Essays.)*

"The aurora," says Captain Parry, "began to show itself as soon as it was dark. Innumerable streams of white and yellowish light, occupied the heavens to the southward of the zenith, being much brighter in the south east from which it often seemed to emanate. Some of these streams were in right lines, others crooked, and waving in all sorts of irregular figures, moving with inconceivable rapidity in various directions. Among them might frequently be observed shorter bundles of rays, which moving even with greater velocity than the rest, have acquired the name of 'merry dancers.' In a short time the aurora extended itself over the zenith, about half way down to the northern horizon, but no further, as if there were something in that quarter of the heavens that it did not dare to approach. About this time, however, some long streamers shot up, from the horizon in the north-west, but soon disappeared. While the light extended over part of the northern heavens, there were a number of rays assuming a circular or radiated form, near the zenith, and appearing to have a common centre near that point, from which they all diverged. The light of which these were composed, appeared to have inconceivably rapid motion in itself, though the form it assumed, and the station it occupied in the heavens, underwent little or no change for perhaps a minute or more. This effect is a common one with the aurora, and puts one in mind, as far as its motion alone is concerned, of a person holding a long ribbon by one end, and giving it an undulatory motion through its whole length, though its general position remains the same. When the streams or bands were crooked, the convolutions took place indifferently in all directions. The aurora did not continue long to the north of the zenith, but remained as high as that point, for more than an hour. After which, on the moon rising, it became more and more faint, and at half-past eleven was no longer visible.

"The colour of the light was most frequently yellowish white, sometimes greenish, and once or twice a lilac tinge was remarked, when several strata appeared as it were to overlay each other by very rapidly meeting, in which case, the light was always increased in intensity. The electrometer was tried several times, and two compasses exposed on the ice during the continuance of this aurora, but neither was perceptibly affected by it. We listened attentively for any noise that might accompany it, but could hear none; but it was too cold to keep the ears uncovered very long at one time. The intensity of the light was something greater than that of the moon in her quarters. Of its dimming the stars there cannot be a doubt. We remarked it to be in this respect, like drawing a gauze veil over the heavens in that part, the veil being most thick when two of the luminous sheets met and overlapped. The phenomenon had all the appearance of being full as near as many of the clouds commonly seen, but there were none of the latter to compare them with at the time."

Although Captain Parry did not observe any electrical or magnetic disturbances, during the aurora, of which he gives the above description, yet both were noticed by Captain Franklin. *(Journey to the shores of the Polar Sea.)* A hissing sound was also heard by

Nairne, Cavallo, and others. There can be no doubt, therefore, that the phenomenon is to be ascribed, in a great measure, to the operation of natural electricity.

I shall conclude this Lecture with a few remarks on the two electrical theories—my observations shall be brief, for as these lectures are intended to be entirely of a popular character, it is my wish to avoid as much as possible entering into scientifically debateable subjects. It would, nevertheless, be improper to conclude this branch of electricity without noticing the two hypotheses which have been proposed, to account for its production.—The following, then, is a general exposition of these theories.

1st. *Theory of two electric fluids.*—This was proposed partly by Dufay, and partly by Symmer. t assumes, that every body in an unexcited state, contains two distinct fluids, equally subtle, equally elastic, and equally diffusive; each repulsive to its own particles, but attractive to those of an opposite kind; these attractive and repulsive forces, being exactly equal at the same distance, and both varying inversely as the square of the distance; the fluids are distinguished by the terms *vitreous* and *resinous*. When bodies are in a quiescent state, these two electricities are supposed to be combined and neutralized; but when excited, which we have seen can be done by various means, there is an excess of *one* fluid, and the body is said to be electrified. Suppose two bodies, A, and B, to be brought near each other, each fluid in the one, will repel the fluid of the same name in the other; but then attraction to the same amount, exists between the opposite fluids, and no change results; let them now be rubbed together, and a portion of the combined electricities in both, will become decomposed; the separated resinous fluid will be transferred to one of them, say to A, and the vitreous to B; each being electrified to the same degree, though oppositely.

The pressure of the non-conducting, surrounding atmosphere, confines either fluid to the body, to which it has been by excitation transferred; it would otherwise, by its ideo-repulsive power, quit it altogether. But the opposite electricities on each body powerfully attract each other, and have a tendency to force their way across the intervening stratum of air, to bring A and B into contact: if they succeed in effecting this, they reunite, and the electric equilibrium is restored.

But if A and B are similarly electrified, then the tendency of the electric fluid to escape in opposite directions, causes the bodies to fly asunder, if the repulsive force exceeds their weight, and thus produces electric repulsion.

2nd. *Theory of a single fluid.*—The founder of this theory was the celebrated American philosopher, Dr. Franklin. It supposes a single electric fluid, the particles of which repel each other, with a force diminishing as the squares of the distance, and are attracted by matter according to the same law. Unelectric material substance is composed of electricity and matter, combined with, and neutralizing each other; it is also necessary to assume that ponderable matter *repels itself*, in the same manner, and according to the same law, as the particles of electricity. The application of these postulates is easy enough. Unelectric bodies are such as have their natural quantity of electricity, which is exactly sufficient to saturate and neutralize the matter of which they consist. They are then electrically indifferent; because the repulsion exerted between the electricity and matter of contiguous bodies is exactly counteracted by the attraction of the electric fluid in each, for the matter of the other. Electrical excitement is occasioned by an excess or deficiency of this natural quantity of electricity. When glass is rubbed by a woollen cloth, it acquires an addition to its natural share, and the cloth, a corresponding deficiency; these two opposite states are named *positive* and *negative*. Bodies positively excited, repel each other by means of the repulsion among the particles of the electricity with which they are surcharged; and the equal tendency of negatively excited bodies to separate, is ascribed to the mutual repulsion among the particles of matter. The electric equilibrium is restored by the electricity escaping from those bodies where it is in excess, and passing to those that are undercharged.

To this theory it is objected, that it involves an assumption at variance with the laws of gravitation, namely, that of matter being repulsive to itself. It requires also a repulsive fluid superadded to matter, and freely moveable amongst its particles to explain satisfactorily the unequal distribution of the electric energy over the surface of electrified bodies, as well negative, as positive, dependant on their form. But, as Dr. Turner observes, with this addition, the theory of Franklin would virtually cease to be that of a single electric fluid.

On the whole however, when viewed merely as hypotheses calculated to facilitate our comprehension of the phenomena, and of their connexions, it is a matter of indifference which we employ, for either of them will answer the purpose.

The following abstract of a paper read before the Royal Society, on the 11th of January, 1838, by Professor Faraday, is too important to be omitted. I regret that a notice of it was not published in time to be inserted in its proper place in the last lecture.

The object of this paper is to establish two general principles relating to the theory of electricity, which appear to be of great importance; first, that induction is in all cases, the result of the action of contiguous particles. And, secondly, that different insulators have different inductive capacities.

I shall briefly describe the results, which he conceives, cannot but be admitted as arguments against the received theory of induction, and in favour of that which he has put forth.

Dr. Faraday was led to imagine that electrical action at a distance, (which is what is meant by the term *induction*,) never occurs except through the intermediate agency of intervening matter, from the discovery he had already made of the law, by which bodies subjected to electrical action, (electrolytes) refuse to yield their elements to a current, when in a solid state, though they give them forth freely when liquid. To test the correctness of this view, he commenced by tracing the course of inductive action, for if it were found to be exerted in *curved lines*, it would naturally indicate the action of contiguous particles, and would scarcely be compatible with action at a distance.

The first experiments were conducted on a very large scale. An insulated cube twelve feet in the side, consisting of a wooden frame, with wire net work, every part of which was brought into good metallic contact by bands of tin foil, had a glass tube, containing a wire, in contact with a large electrical machine, passed through its side, so that about four feet of the tube entered within the cube, and two feet remained without. But it was found impossible, in any way, to charge the air within this apparatus with the least portion of either electricity, thus proving that it is not possible to communicate to a body, an absolute charge of *one* species of electricity.

For investigating the question, whether induction is an action of contiguous particles, Faraday employed as an electrometer, the torsion balance of Coulomb, with certain alterations and additions. A brass ball being laid on the top of an excited cylinder of shell-lac placed vertically, the charge which a carrier ball received when brought to different points near the brass sphere, was measured by means of the electrometer; and it was inferred from the character of the electricity, that the charge was one by induction, and from its measure, that it proceeded in curved lines. By substituting for the brass sphere, a disc of metal above the shell-lac cylinder, it was found, that when the carrier ball was brought near to the middle of the disc, no charge was communicated, although a sensible one was obtained at the edge of the disc, and also at a point above its centre, further removed from the excited cylinder. Corresponding, and very striking results were obtained, when a brass *hemisphere* was placed on the top of the cylinder of lac. The charge communicated at the centre of the hemisphere, was only one-third of that obtained at the edge of its periphery; but by taking it at a point at some height above the centre, and consequently much further removed from the inducing cause, the charge was nearly equal to that of the periphery. Here, the author remarks, the induction fairly turned a corner, exhibiting both the curved lines, or courses of its action when disturbed from their rectilineal form, by the shape, position, and condition of the metallic hemisphere; and also a lateral tension, so to speak, of these lines on one another, all depending on induction, being an action of the contiguous particles of the dielectric thrown into a state of polarity and tension, and mutually related by their forces in all directions. The same results were obtained with fluid and solid dielectrics.

For investigating the question of specific inductive capacity, Dr. Faraday employed two hollow brass spheres of very unequal diameters, the smaller placed within the larger, and concentric with it; the interval between the two being the space through which the induction was to be effected. The apparatus had a tube in the lower part furnished with a stop cock, by means of which it might be connected with an air pump, or filled with any required gas. In place of the lower hemispherical shell of air, occupying the interval between the two spheres, any solid dielectric of the same form, such as shell-lac, glass, or sulphur might be substituted. Two of these instruments precisely similar in every respect, were constructed, and the author ascertained that the inductive power was the same in both, by alternately charging each, and dividing the charge with the other, and finding that in all cases, the charge remaining in the one, and also that received by the other, was very nearly half the original charge.

With this apparatus Dr. Faraday proved that the conclusion drawn from the former experiments of Coulomb, from which it appeared that a wire surrounded by shell-lac, took exactly the same quantity of electricity from a charged body, as the same body took in air; and consequently, that both these dielectrics have the same inductive capacity, is not to be maintained, the mean of several experiments shewing that the inductive capacity of shell-lac is to that of air as 2 to 1; that of flint glass, as 1·76 to 1; and that of sulphur, as 2·24 to 1.

In conclusion, the author remarks, that induction appears essentially to be an action of contiguous particles, through the intermediation of which, the electric force originating or appearing at a certain place, is propagated to, or sustained at a distance, appearing there as a force of the same kind, and exactly equal in amount, but opposite in its direction and tendencies. Induction requires no sensible thickness in the conductors, which may be used to limit its extent; for an uninsulated leaf of gold may be made very highly positive on one surface, and as highly negative on the other, without the least interference of the two states, as long as the induction continues. But with regard to *insulating media*, the results are very different; for their thickness has an immediate and important influence on the degree of induction. As to their quality, though all gases and vapours are alike, whatever be their state, amongst solid bodies, and between them and gases, there are differences which prove the existence of specific inductive capacities.

LECTURE III.

ON GALVANISM.

THE science of galvanism, which, from the preliminary information on the subject of electrical excitation, which we have acquired, we shall be enabled to investigate, owes its name and origin to the experiments on animal irritability, made in 1790, by Galvani, a professor of anatomy at Bologna. These experiments were suggested by the following circumstance:—

It happened that the wife of the Professor being consumptive, was advised to take, as a nutritive article of food, some soup made of the flesh of *frogs*. Several of these creatures recently killed and skinned, were lying on a table in the laboratory, close to an electrical machine, with which a pupil of the Professor was making experiments. While the machine was in action, he chanced to touch the bare nerve of the leg of one of the frogs, with the blade of a knife that he held in his hand, when suddenly the whole limb was thrown into violent convulsions. Galvani was not present when this occurred, but received the account from his wife, and being struck with the singularity of the phenomenon, he lost no time in repeating the experiment, and investigating the cause: he found that it was only when a spark was drawn from the prime conductor, and when the knife or any other good conductor, was in contact with the nerve, that the contractions took place, and pursuing with unwearied industry his investigations, he at length discovered that the effect was independent of the electrical machine, and might be equally well produced, by making a metallic communication between the outside muscle and crural nerve. Galvani had previously entertained notions respecting the agency of electricity in producing muscular action, so these new experiments, as they seemed to favour his views, had with him more than ordinary interest. He immediately ascribed the convulsive movements in the limb, to electrical agency, and explained them by comparing the muscle of an animal, to a Leyden phial, charged by the accumulation of electricity on its surface; while he imagined that the nerve belonging to it, performed the function of a wire communicating with the interior of the phial, which would of course, be charged negatively. In this state of things, if a communication, by a good conductor, were made between the muscle, and nerve, a restoration of the electric equilibrium, and a contraction of the fibres would ensue.

These experiments excited much attention among the men of science at that period; they were repeated and varied in almost every country in Europe, and ascrideb to various causes. Some imagined them the effect of a new and unknown agent; others adopted the views of the discoverer, and recognized them as peculiar modifications of electricity; but as experiments multiplied, analogies increased, and at length the discovery of the Voltaic pile removed every doubt on the subject, and the identity of electricity and galvanism was established.

Professor Volta of Pavia, was the philosopher who had the merit of having successfully combated the original explanation of Galvani, and proved its fallacy. He maintained that electric excitement is due solely to the metals, and that muscular contractions are occasioned by the electricity thus developed passing along the nerves and muscles of the animal.

To Volta's experiments we are indebted for the first galvanic * instrument, namely, the voltaic pile; it was described by him in the Philosophical Transactions of 1800, and to him, therefore, the merit of laying the foundation of this highly interesting branch of science is due. The main difference between common and galvanic electricity, (which are due to the same force excited under different conditions,) will be found as we proceed to be this: the first produces its effects by a comparatively small quantity of electricity, insulated, and in a high state of *tension*, that is, having remarkable attractive and repulsive energies, and power to force its way through obstructing media; the latter is more intimately associated with other bodies, is in *enormous quantity*, but never attains a very high state of tension, and exhibits its effects while flowing in a continuous stream, along conducting bodies.

We will first direct our attention to the nature of those arrangements which are the sources of galvanic power.

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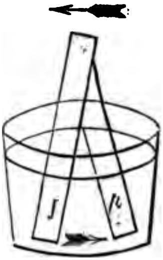
* The term Galvanism is generally used in honour of the *first* discoverer of this branch of electrical science. The term Voltaism is also frequently used in honour of Volta the *real* founder.

If we take two equal sized plates of copper and zinc, each furnished with a glass handle for insulation, and bring them into contact, holding them by the glass, it will be found by appeal to the condenser, after their removal, that there is a slight accumulation of positive electricity on the zinc, and an equal negative charge on the copper; the quantity is extremely small, and it requires a good instrument to exhibit it. If the same experiment be made in vacuo, or in perfectly dry hydrogen or nitrogen gas, no electricity whatever can be discovered, hence it is inferred that the development of the small quantity of electricity when the plates are brought into contact in atmospheric air, is due to the slight chemical action of the oxygen of the air on the zinc, occasioned by its compression by the copper. This explanation has been long combated by various men of science, but it seems to me indisputably verified by the late experiments and observations of M. de la Rive, published in the sixty-seventh number of the London and Edinburgh Philosophical Magazine. He there shows that electricity is produced by the most feeble, and almost imperceptible chemical action, and hence accounts for the errors into which other physicists have fallen; it being extremely difficult to ensure the absence of such exciting causes. I shall have occasion to refer to this valuable paper again in the next lecture.

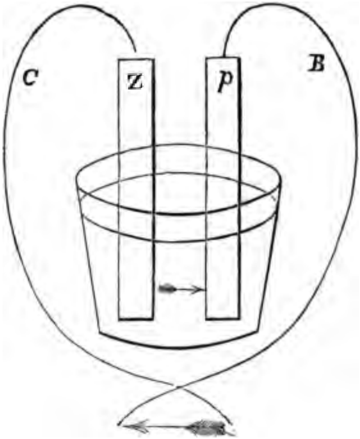
It will be evident that if electricity can be excited by such trifling chemical action on metals, great increase of chemical action must give rise to considerable augmentation of electrical action.

Fig. 17.



If we take two plates of different kinds of metal, platina and zinc, (*Figs.* 17, 18,) for example, and immerse them in pure water touching each other; a galvanic circle is formed, the water will be slowly decomposed, its oxygen will become fixed on the zinc, (the oxidable metal) and at the same time a current of electricity will be transmitted through the liquid to the platina, on the surface of which, the other element of water, namely, the hydrogen, will make its appearance in the form of minute gas bubbles; the electrical current passes back again into the zinc at the points of its contact with the platina, and thus a continual current

Fig. 18.



is kept up; and hence it is called a galvanic circle. The moment the circuit is broken by separating the metals, the current ceases; but is again renewed on making them again touch, either in or out of the water.

If a small quantity of sulphuric acid be added to the water, the phenomena will become much more apparent, for the chemical action on the zinc will be increased, and the liquid made a better conductor. The bubbles of hydrogen gas will now be seen to rise rapidly from the decomposed water on the surface of the platina, and the zinc, (if it be pure) will be tranquilly dissolved. It matters not how the communication between the metals is made, whether they touch beneath the liquid, or above it, or by means of a wire of any length; all that is necessary, being that both should be in the same liquid, and not acted on in an equal manner by it. The greater the difference between the metals in this respect, the greater will be the quantity of electricity developed; hence platina and zinc are peculiarly appropriate: the former not being chemically acted on in the slightest manner by diluted sulphuric acid; while the latter is attacked energetically. This is called a *simple* galvanic circle.

If a plate of copper (which may be substituted for the platina, with very little loss of effect,) and another of zinc, are soldered together, and cemented into a wooden bottomed box with metal sides, so as to form two separate cells; then no current will pass, on diluted acid being poured into the cells, unless communication is established between them by means of moistened thread or metal wire, in which case, the current will, as usual, pass from the zinc through the conducting medium into the copper. Or the two plates may be connected by a wire and immersed in a solution, divided by a plate of glass.

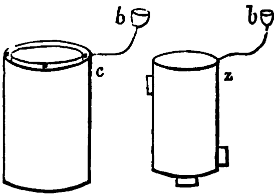
It does not require two metals to form a galvanic circle, or even two different liquids, if other conditions are attended to. A current is established, when a zinc plate is cemented into a box, and acted upon on one side by diluted acid, and upon the other side by common salt; or by acting on both sides by the same acid, one surface being rough, and the other smooth, metallic communication between the two cells, being, of course, formed by a wire. Common zinc affords a good illustration of a simple galvanic circle; this metal usually contains about one per cent of iron, mechanically diffused over its surface. On immersion into dilute sulphuric acid, these small particles of iron and zinc form numerous voltaic circles, transmitting their current through the acid that moistens them, and liberating a large quantity of hydrogen gas. Pure zinc, that is, zinc distilled, or the common metal amalgamated, by rubbing it over first with diluted nitric acid, and then with quicksilver, is very slowly acted upon by diluted sulphuric acid, and hence is usually employed in galvanic researches.

An important fact, of which a beautiful practical application was attempted by Sir H. Davy, was early observed:—In proportion as the contact of two metals in an acid or saline solution increases the affinity of one of them, for one element of the solution, it diminishes the ability of the other metal to undergo change. Thus, when zinc and copper are united in diluted acid, the zinc is acted upon *more*, and the copper *less* than if they were immersed separately. A sheet of copper undergoes rapid corrosion in sea water, the green oxy-chloride (commonly called the submuriate) of copper is formed; but if it is associated with another metal more electro-positive than itself, such as zinc, it is preserved, and the zinc undergoes a chemical change. Davy found that the quantity of zinc requisite to effect a complete preservation of the copper, was proportionally very small. A small round nail will preserve forty or fifty square inches, wherever it may be placed. And he found that with several pieces of copper connected by filaments the fortieth of an inch in diameter, the effect was the same. Sheets of copper defended by $\frac{1}{40}$th to $\frac{1}{1000}$th part of their surface of zinc, malleable, and cast iron, were exposed during many weeks to the flow of the tide in Portsmouth harbour, and their weight ascertained before and after the experiment. When the metallic protector was from $\frac{1}{40}$th to $\frac{1}{150}$th, there was no corrosion or decay of the copper; with $\frac{1}{200}$th to $\frac{1}{460}$th there was a loss of weight; but even $\frac{1}{1000}$th part of cast iron saved a portion of the copper. Davy hoped to apply this principle to the preservation of the copper sheathing of ships; but unluckily it is found, that unless a certain degree of corrosion takes place in the copper, its surface becomes foul from the adhesion of sea weeds and shell fish.

The oxy-chloride formed when the sheathing is unprotected, acts probably as a poison to these plants and animals, and thus preserves the copper free from foreign bodies, by which the sailing of the vessel is materially retarded.

There are many modifications of the simple galvanic circle; among the most useful of which is the cylindrical battery, which consists of a double cylinder of

Fig. 19.



copper closed at the bottom to contain the acid; and a similar, but smaller cylinder of zinc, which is kept from touching the sides of the copper by pieces of cork; both are furnished with wires terminated by cups, to contain mercury for the convenience of making and breaking the circuit. In order to understand the phenomena presented by these arrangements, it is necessary to bear in mind the important distinction before made between *electricity of tension*, accumulated on surfaces, and manifesting itself by attractions and repulsions, and by discharges passing through air, and *electricity in motion.* In these simple voltaic circles, the intensity of the electricity is remarkably low. It requires very delicate gold leaf condensers to render it at all sensible, but the quantity is very great; so much so, that when it is made to traverse a fine platina wire it becomes immediately ignited, and *even fused;* and a thick wire when used to break and renew the contact between the plates, gives rise to a brilliant spark.

This is shown by the instrument in *Fig.* 20, which at first sight seems to resemble a compound arrangement, but which will be found on examination to be precisely the same with respect to action, as a single pair of plates, although in reality it consists of seventeen copper and sixteen zinc. The copper plates are united together by slips of the same metal attached to each; and the zinc plates by a band of varnished zinc passing along the bottom; contact between the dissimilar metals is prevented by the interposition of bits of

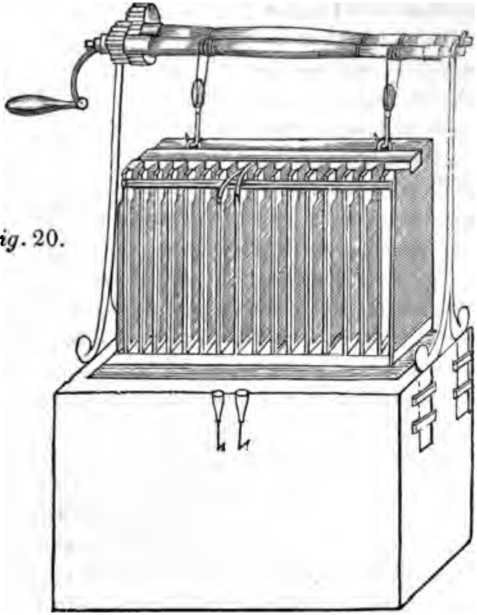


Fig. 20.

cork; and the whole is firmly cemented into a stout frame work of varnished wood; it is let down into, and drawn up from the trough containing the exciting liquid, by ropes passing over rollers, and working one in the other by unequal sized cog wheels, turned by a handle; two stout brass wires are soldered to the centre copper and zinc plates, which being bent twice at right angles, dip into two glass tubes* containing quicksilver; the circuit is completed by establishing a communication between the two mercury *tubes*, and as the wires are so adjusted, that the moment the plates touch the liquid in the trough, the ends of the wire shall be immersed in the quicksilver, it is evident that the quantity of electricity may be regulated by immersing the plates wholly, or in part into the liquid; this is particularly useful for experiments in electro-magnetism, for which the battery was originally constructed. The introduction of the "sustaining" or "constant" batteries of Messrs. Daniell and Mullins, has, however, entirely superseded the employment of these simple circles in electro-magnetic investigations. Of these batteries I shall speak more fully presently.

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* These tubes are not shown in the figure, the introduction of the "sustaining" battery of Daniell described further on, having superseded the employment of these simple circles in electromagnetic experiments, and the instrument is here exhibited as a deflagrator.

The quantity of electricity set in motion by these simple circles, when on a large scale, is very great, but the intensity is very low; they will not give shocks, nor decompose water: their heating effects are however so immense, that they are called *calorimoters.*[*] An arrangement on a very extensive scale, was made under the direction of Mr. Pepys, at the Royal Institution. A sheet of zinc, and one of copper were coiled round each other, each being sixty feet long, and two wide; they were kept asunder by the intervention of hair ropes, and suspended over a tub of acid, so that by a pulley they could be immersed and removed. This instrument is capable of heating to redness several feet of platina wire. The energy of the simple circle depends on the size of the plates, the intensity of the chemical action on the oxidizable metal, the rapidity of its oxidation, and on the speedy removal of the oxyd.

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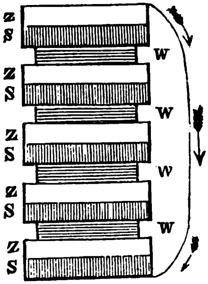
[*] This name was suggested by Dr. Hare, of Philadelphia, who first constructed the simple circle on an extensive scale, and observed its surprising power of igniting metals.

In order to increase the intensity of the electrical current, with a view to the exhibition of its chemical and physiological effects, we resort to an increase in the number of the plates, without paying any or but little regard to their size; an arrangement of this sort is called *a compound galvanic circle.* It was mentioned above as having been originally devised by Volta, and hence called the voltaic pile.

The original instrument consisted of a series of silver and zinc plates, arranged one above the other, with moistened flannel or pasteboard between each pair. A series of thirty or forty alternations of plates, four inches square, will cause the gold-leaf electroscope to diverge; the zinc end with positive, and the silver end with negative electricity; a shock will also be felt on touching the extreme plates with the fingers when moistened with water.

Fig. 21.



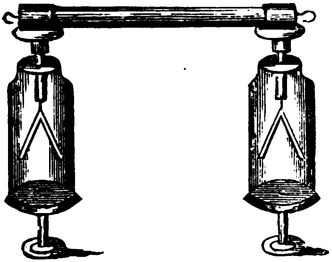
These latter effects are much increased when the flannel or pasteboard is moistened with *salt* water: in this case a spark will be seen on bringing the extreme wires into contact, and water will be decomposed; hence we see that the increase of chemical action by the addition of the salt, materially increases the *quantity* of the electricity set in motion; but the pile will not in any sensible manner increase the divergence of the gold-leaves, its *intensity* therefore is not materially augmented.

An electric pile was constructed by De Luc, from which much useful information respecting the direction of the electric current in these cases of excitation, may be derived. This instrument consists of a number of alternations of two metals, with paper interposed; the elements may be circular discs of thin paper, covered on one side with gold or silver-leaf, about an inch in diameter, and similar sized pieces of thin zinc foil, so arranged that the same order of succession shall be preserved throughout, viz.: zinc, silver, paper, zinc, silver, paper, &c.

About five hundred such alternations enclosed in a perfectly dry glass tube, terminated at each end with a brass cap and screw, to press the plates tight together, will produce an active column. Mr. Singer has however, constructed one on a much more extensive scale. It consisted of twenty thousand series of silver, zinc, and double discs of writing paper; it was capable of diverging pith ball electroscopes, and by connecting one extremity of the series with a fine iron wire, and bringing the end of this near the other extremity, a slight layer of varnish being interposed, a *succession of bright sparks was produced*, especially when the point of the wire was drawn lightly over the varnished surface. A very thin glass jar containing fifty square inches of coated surface charged by ten minutes contact with the column, had power to fuse one inch of platina wire, one five-thousandth of an inch in diameter. It gave a disagreeable shock, felt distinctly in the elbows and shoulders, and by some individuals across the breast. The charge from this jar would perforate thick drawing paper, but not a card. It did not possess the slightest chemical action, for saline compound, tinged with the most delicate vegetable colours, underwent no change, even when exposed for some days to its action.

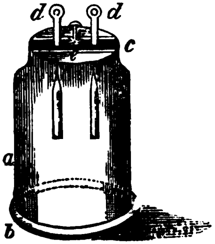
On examining the electrical state of the "electric column," it will be found to resemble that of a conductor under induction; in the centre it is *neutral*, but the ends are in opposite electrical states; and if one extremity be connected with the earth, the electricity of the opposite end becomes proportionally increased; the zinc extremity is positive, and the silver or gold extremity negative; as may be proved by laying the column on the caps of two gold-leaf electroscopes, placed at a distance from each other, the leaves will diverge with opposite electricities; if a communication be made between the instruments by a metallic wire, the divergence of the leaves will cease, but is again renewed when such communication is broken.

Fig. 22.



It is better for these experiments to employ an electroscope in which the gold leaves are suspended singly, (as shown in *Fig.* 23,) and so arranged, as to admit of their being brought nearer to, or carried further from each other. If in such an instrument, the leaves are adjusted at a proper distance from each other, and the wire from which one is suspended connected with the zinc end, and the wire from which the other is suspended

Fig. 23.



connected with the silver end of the column, a kind of perpetual motion will be kept up between the leaves, for being oppositely excited, they will attract each other; and having by contact annihilated their electricities, they will separate for a moment, and again attract and separate as before. If both silver ends, or both zinc ends of the columns are connected with the two gold leaves, a continued repulsion will be kept up between them, being then similarly electrified.

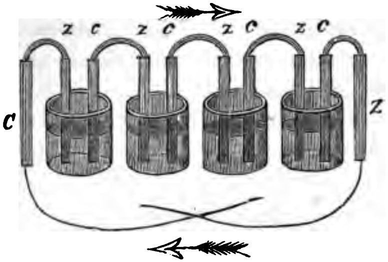
A variety of amusing experiments have been devised, dependent upon this curious property of M. De Luc's column. Thus a small clapper may be kept constantly vibrating between two bells. This contrivance was invented by Mr. Forster, who constructed a series of fifteen hundred groups, and by its continued action kept up the vibrations of the pendulum for a very long time. · With twelve hundred groups arranged by Mr. Singer, a perpetual ringing during fourteen months was kept up, excepting on one occasion, when the instrument was removed from one room to another. And De Luc states, that he had a pendulum which had constantly vibrated between two bells for more than two years, and which still continued in motion at the time of his report. *(Singer.)*

The action of the electric column is kept up solely by the presence of moisture in the paper, for it does not take place at all when the paper is thoroughly and perfectly dry; and though the process of oxidation is very slow, yet the more oxidable metal is in process of time found to be tarnished. It seems also that the state of the atmosphere is in some way concerned with the phenomenon, for the motion of the pendulum is subject to much occasional irregularity. De Luc and Mr. Hausman both observed, that the action of the column was increased when the sun shone on it; but they conceived the effect not to be due to the heat of the sun's rays, because it was found that an instrument put together after the parts had been thoroughly dried by a fire, had no power whatever, but that it became efficacious after it had been taken to pieces, and its materials had remained exposed all night to the air, from which the paper imbibed moisture. Mr. Singer however, remarks, that the power of the column is increased by a moderate heat, as his apparatus vibrated more strongly in summer than in winter, and the electrical indications were stronger when there was a fire in the room. The same experimentalist thinks, that the action of a column constructed with care will be permanent, although it is evident that moisture is indispensable. He states that he had several as active at the end of three years, as when first constructed. He observes also, that care should be taken not to allow the ends to remain for any length of time in contact with a conducting body, for after such continued communication, a loss of power will be perceived. When therefore the instrument is laid by, it should be insulated; and if it had previously nearly lost its action, it will usually recover it after a rest of a few days.

The electric column may serve as a connecting link between the phenomena of ordinary and voltaic electricity. I shall now return again to the latter.

It is easy to see that many inconveniences must attach to the pile of Volta, when the plates are numerous; in addition to the trouble of building it up, it is frequently rendered comparatively inactive, by the moisture pressed out of the lower part, by the weight of the upper; hence the substitution of troughs and other forms of apparatus. The most simple and easily arranged is the "*couronne des tasses;*" which consist

Fig. 24



in a row of small glasses or cups, containing very diluted sulphuric acid: in each of which is placed a small plate of copper, about two inches square, and another similar sized plate of zinc, not touching each other, but so connected, that the zinc of the first glass may be in metallic communication with the copper of the second, and the zinc of the second, with the copper of the third, and so on throughout the series. By this arrangement, (if glasses are employed) we can see what is going on in each cell; and it will be observed, that when the wires are connected, and consequently a current passing, all the metallic surfaces are active, but that when the connection between the extremes or poles is broken, the copper ceases to evolve gas, and it is much more sparingly elicited from the zinc. A few ounces of copper and zinc arranged in this manner, in a series of small gallipots, will serve for the performance of a variety of extremely interesting experiments. Eighteen or twenty groups will rapidly decompose hydrochloric (muriatic) acid, and acidulated water; thirty will give a shock; and a series of two hundred will perform nearly all the experiments usually exhibited with much more extensive instruments. Numerous are the modifications of the couronne des tassses; some of the most useful of these I shall describe before I give an account of their general effects, or explain the rationale of their action.

The first important modification was that suggested by Dr. Babington.* The plates of copper and zinc,

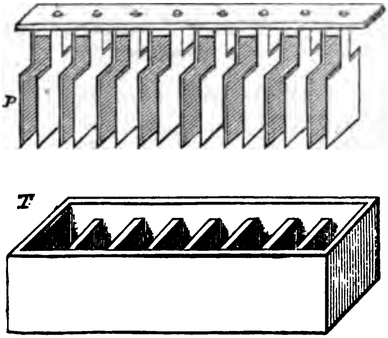


Fig. 25

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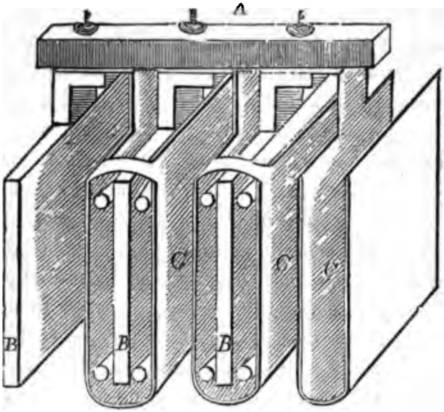
* The galvanic trough with non-conducting divisions, although usually described as the invention of Dr. Babington, was first introduced by my friend, Dr. Wilkinson, in the year 1804. He published a description of it in 1808, in Tilloch's Magazine; referring to Mr. Eastwick, in Aldersgate-Street, who was then a manufacturer of galvanic apparatus. It was in consequence of this reference, that Sir H. Davy and Mr. Children employed Mr. Eastwick, to construct their extensive apparatus, on the same principle. It was Dr. Wilkinson also, who first exhibited the splendid charcoal light with the galvanic battery; and who first effected the fusion of steel wire, on the large scale; he employed nearly a ton weight of metal, and fused many feet at a time.

usually about four inches square, are united together in pairs by soldering at one point only. The trough into which they are immersed is made of earthenware, and divided into ten or twelve equal partitions. The plates are attached to a strip of wood, and so arranged that each pair shall enclose a partition between them: by this means the whole set may be lifted at once into or out of the cells; and thus while the fluid remains in the trough, the action of the plates may be suspended at pleasure, and when corroded, easily replaced. The piece of wood to which the plates are attached, should be well dried and then varnished, in order to render it a non-conductor of electricity. When several of these troughs are to be united together, it is necessary to be extremely cautious in their arrangement, as a single trough reversed will very materially diminish the combined effect. Great care should also be taken to insure perfect communication between the several plates.

The great battery belonging to the Royal Institution is constructed on the above plan; its power is immense; it consists of two thousand double plates, and the whole surface is one hundred and twenty-eight thousand square inches.

In the year 1815 a great improvement in the construction of voltaic batteries was made by Dr. Wollaston. It consists in doubling the copper plate so as to oppose it to both surfaces of the zinc, as shown in *Fig.* 26. This form of apparatus is now generally adopted, where it is an object to combine *quantity* with *intensity*. Ten or twelve troughs upon this construction will be found quite sufficient for all ordinary experiments. The plan also supersedes the necessity of being provided with batteries of large plates. A

Fig. 26.



further extension of the copper would be attended with a considerable increase of power, as appears from the experiments of Mr. Christopher Binks, detailed in Brewster's Journal, for July, 1837. He remarks that, whatever may be the care taken to procure two plates of zinc of an uniform size and thickness, and however alike the attendant circumstances may be, no two couples will be found to give the same results in the same time, when associated with corresponding copper plates, and acted on by acids in the usual way. While one plate will lose perhaps ten grains, another apparently similar will lose five or six grains, and another fifteen or sixteen in the same time; these differences are independent of accidental differences in the distances of the plates from one another; zinc plates he finds also lose less the first time of immersion, than during the second and third.

Mr. Binks appears to have devoted a great deal of time to this subject, and the results of his experiments are very important. In testing the amount of action, he always resorted to the meter or balance, and never to the magnetic needle. I shall give here an abstract of his paper, as it may serve as a guide in the construction of voltaic apparatus.

An equality in the extent of surface does not insure an equality of voltaic action, nor does that action increase in the same ratio, as the surface may be increased, as has hitherto been believed; for this reason Mr. Binks always estimated the amount of action on the zinc plates used in his comparative experiments by previous immersion in an acid, similar to that intended to be used, which was generally a mixture of four and a half by measure of sulphuric acid with one hundred water.

He first determined the proportion of copper to zinc most favourable to voltaic action. The following table shows the results, a fresh zinc amalgamated plate being employed each time.

			grs.
1st.	Copper equal to zinc,	loss	4·0
2nd.	..	twice the zinc	5·2
3rd.	..	four times the zinc	6·6
4th.	..	eight times the zinc	8·7
5th.	..	twelve times the zinc	14·5
6th.	..	sixteen times the zinc	18·5
7th.	..	twenty times the zinc	15·0
8th.	..	twenty-four times the zinc	14·8

This shows that the greatest amount of action, and consequently the greatest development of electricity, is when the copper is *sixteen* times the size of the zinc, and if we take 4·0 grains loss of zinc as a standard, and compare the other results with it, we shall find the energy of the simple voltaic circle is increased about four and a half times by employing the metals in that proportion, namely, sixteen to one.

This experiment was varied by removing the plates from one inch to two inches from each other, and again by strengthening and weakening the exciting fluid, still the results were comparatively the same. He also tried whether the increased effect was due to the *surface* or *mass* of the copper, the result was, that when a solid prism of copper weighing two pounds was employed, 7·2 grains of zinc were expended, but when the same weight of *sheet* copper was joined to the same zinc plate, the expenditure was increased to 16·5 grains. He thus verified what was before the general opinion.

It is rather curious that we have in this law an exact correspondence with the specific gravities of the two gases involved in its operation, the specific gravities of oxygen and hydrogen are as sixteen to one. This seems something more than a mere coincidence.

In these experiments the copper did not surround the zinc, but was placed opposite one face only. Mr. Binks proceeds to examine whether the action on the zinc took place on that surface only that was next to the copper, or over the whole surface, and whether any thing is gained by placing copper opposite the other surface also—he found *not*—for a plate with copper sixteen times its size placed on one side only, lost twelve grains, the same with double that quantity of copper, half on each side lost 12·3 in equal time. Again, do both surfaces of the copper operate, or only that one *opposite* the zinc? A copper plate with both sides clean caused the zinc to lose 12·2 grains, when one side was covered with wax 10·5, showing that the outer surface is engaged in the operation but unimportantly so.

The second investigation was to determine the effect of increasing the size of the zinc plate beyond the copper. The following table shows the results of the experiments, the amount of action being estimated *not* by the loss of metal, the plates being too large to admit of their being weighed with sufficient nicety, but by the measure of the hydrogen gas given off from the copper.

			Cub. Inc.
1st,	Copper and zinc, equal, gave hydrogen		0·8
2nd.	Zinc twice the size of the copper	..	1·6
3rd.	Zinc four times	ditto	2·4
4th.	Zinc six times	ditto	2·5
5th.	Zinc eight times	ditto	2·2
6th.	Zinc twelve times	ditto	2·2
7th.	Zinc twenty times	ditto	2·2
8th.	Zinc twenty-four times	ditto	2·2

Taking as before the result of equal plates as a standard, the amount of action gained when the zinc plate is six times larger than the copper, is about three times beyond that produced when the plates are equal.

By this it appears that voltaic energy may be increased when *either* metal is made the larger, but *not* in an equal manner. When the zinc is increased, the maximum effect is arrived at by enlarging it about seven times, and the amount of effect is as three to one, but with copper the maximum effect is not obtained till it is increased sixteen times, and the total absolute amount thereby gained over the equal plates is four and a half.

Mr. Binks then proved that the same laws operate in *compound voltaic batteries.* He prepared three; in the first the copper and zinc were equal; in the second the copper was sixteen times the size of the zinc; and in the third the zinc was seven times the size of the copper. The gases evolved in a given and equal time were as follows:—

From the first	1·2 cubic inch.
From the second	6·8
From the third	4·5

It has been generally understood that the action of any voltaic combination, increases directly as the surface increases; but Mr. Bink's experiments, which he says were varied in every possible manner, show that this is not the case; for on submitting to trial several arrangements of zinc and copper, (the latter sixteen times larger than the former) progressively increasing in size, the sixteenth increase did not lose sixteen times the quantity of metal, but only eight times, or one half; so the increase is *not* as the surface, but in some other unknown ratio.

When two simple arrangements are united, and unequal in size, supposing one to give off in a certain time $3\frac{2}{10}$ cubic inches of hydrogen, and the other 16 cubic inches in an equal time, the action was found to be equally distributed over both, but the total amount of action to be diminished about one half; for when separated, 19·2 cubic inches of gas were given off, and when joined only 8·8 cubic inches. When the arrangements are of the same size and connected, the *combined action* is found to be less, proportionally, than the action in single arrangements; this was unexpected.

This table shews the result of three unequal arrangements.

SEPARATE.	Cub. In.	COMBINED.	Cub. In.
A gave hydrogen	2	A gave hydrogen	3·4
B	9	B	3·4
C	18	C	3·4
Total	29	Total	10·2

What follows is extremely interesting. When the copper and zinc plates were equal in size, it was found that the combined action was *less* than the action in single arrangements; but when the copper was sixteen times the size of the zinc, the case was different, as the following shows:

Three arrangements prepared alike.

WHEN SEPARATE.	Grains.	WHEN JOINED.	Grains.
No. 1, lost zinc	19·9	No. 1, lost zinc	28·8
No. 2,	25	No. 2,	29·3
No. 3,	23·7	No. 3,	28·5
Total	68·6	Total	86.6

Here we find a remarkable increase in the combined action; but even in this case if the arrangements were relatively unequal, a remarkable *decrease of action*, amounting to nearly one half, took place, and this always occurs; so in the construction of batteries it should be a particular object to have all the pairs as nearly as possible of the same size. Practically Mr. Binks has proved this, and M. de la Rive has theoretically explained it in the paper before alluded to, and which will be noticed at greater length in the next lecture. The table underneath gives the result of three experiments with three compound circles; in A, the elementary couples were equal in size; in B, they increased, as 1, 2, 4, 8, 16; and in c, as 8, 9, 10, 11, 12.

	Cub. In.
A yielded of mixed gases (oxygen and hydrogen)	1·3
B, ...	0·7
C, ...	1·1

All these experiments were made with diluted sulphuric acid as the exciting agent, in which case the proportions of 16 copper to 1 zinc, was the most effective. Here the primary phenomena are, the decomposition of water, the combination of its oxygen with the zinc, and the liberation of its hydrogen; but it does not follow that the same proportions are best under other circumstances; when, for example, a solution of sulphate of copper is used, in which case the action is the *reformation* of water, and the *deposition* of metallic copper; or when a mixture of nitric and sulphuric acids is used, in which case water and ammonia is formed within the cells of the batteries. Mr. Binks tried the former of these variations, by immersing the zinc in diluted sulphuric acid, (four and a half acid and one hundred water) and confining it in a membraneous bag, the copper solution surrounding it. He found the greatest effect to ensue *when the copper plate was eight times larger than the zinc* in all cases, and he thinks that a specific and different proportion between the metals would be requisite for every case in which the operation within the cells of the battery differed.

Lastly, the correspondence between the quantity of zinc expended and hydrogen evolved, is not always the calculated and theoretical value, the regularity is observed up to a certain number of pairs; but when the battery becomes powerful enough itself to decompose water, it is no longer maintained. Thus with sixteen small and equal pairs, the quantity of zinc expended was seventy-four grains, and the total quantity of hydrogen evolved sixty cubic inches; now 34·5 grains of zinc are required to produce an equivalent or *one* of hydrogen, and taking one hundred cubic inches of this gas to be 2·1318 grains, we have the measure of an equivalent of hydrogen to be 46·9 cubic inches, therefore the seventy-four grains of zinc expended, should have yielded 100·5 cubic inches of hydrogen, but they actually only yielded 60·6 cubic inches. That the hydrogen is produced, there is no doubt, but it remains to be explained, what purpose it subserves connected with the working of the battery.

The employment of sulphate of copper as the exciting agent in voltaic batteries, instead of acids, is strongly recommended by Mr. Warren De la Rue. In the common method of charging at the moment of the immersion of the plates in the diluted acid (sulphuric) the electricity is produced by the combination of the acid with that portion of oxyd which is in perfect contact with the zinc plate: when this thin coating of oxyd is removed, the zinc plate is then oxydized at the expence of water, hydrogen being set at liberty; and as the hydrogen assumes the gaseous form, as in the formation of steam, it annuls or carries off a large portion of electricity.

Mr. De la Rue remarks, that if sulphate of copper be used in charging the battery instead of acid, oxygen is supplied to the zinc by the oxide of copper, no evolution of gas therefore, except the small quantity attributable to local action takes place; and the action is thus rendered continuous, the effect being fully equal to that *momentarily* produced by immersion in acids.* Experiments may also be conducted with batteries thus charged, which cannot be exhibited at all with the same arrangements excited by acids, the momentary power being exhausted before the battery can possibly be brought into action.

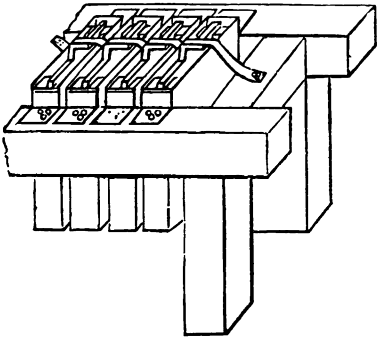


Fig. 27.

Fig. 27, represents a form of battery suggested by Mr. De la Rue, as well adapted to the use of sulphate of copper: it is more economical than any now in use, and possesses this great advantage, that the zinc plates when worn out may be easily replaced.

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* When a battery is first immersed into an *acid* exciting agent, it will ignite small wires placed between its poles, but this heating power continues for a very short space of time; and if the battery be immersed without connecting the poles, and allowed to remain for a few minutes, and the connection then made, with the same length of the same wire, no ignition whatever is produced; this speedy diminution in the quantity of electricity rendered available, *is probably owing* to the evolution of hydrogen gas.

Fig. 28.

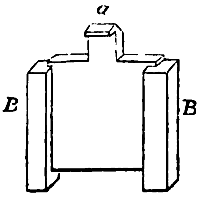


Fig 28. shows the zinc plate which must be *tinned* on the top *a*, prior to the amalgamation of the rest of the plate; this is effected by filing the top smooth, wiping it over with a little muriate of ammonia, and then dipping the top into a ladle of melted tin, a little tallow being placed on the tin to prevent the surface from oxidizing. BB are two slips of wood grooved out to within three fourths of an inch of the bottom, and intended to retain the zinc plate in its proper position. The copper plates are formed into cells as represented in *Fig.* 29, five inches square and one inch wide; EE are two ears of copper, by which the cell is suspended in its place: A is a slip of copper to form a connection by means of solder to the zinc plate in the adjoining cell. The cells are painted on the outside to protect them from the action of the acid. The zinc plates do not descend lower than within three-fourths of an inch of the bottom of the cells, so that the space left may contain the deposit resulting from the decomposition of the sulphate of copper. The cells are supported in a long wooden frame by the ears EE, and retained in their place by tacks driven through them, as represented in the figure.

Fig. 29.

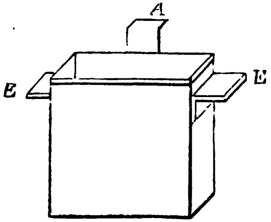


Fig. 30.

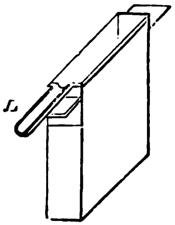


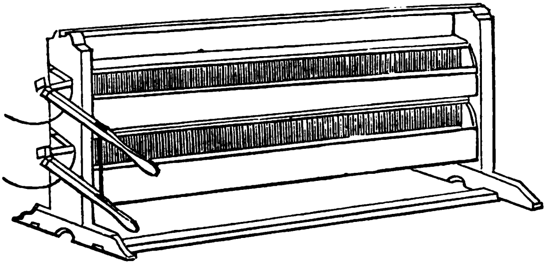
Fig. 30 represents a contrivance by which the charge may be renewed while the battery is in action; at the top of each cell may be placed a lip or spout L, a quarter of an inch deep, which must overhang a wooden gutter, running the length of the frame. The solution must be renewed by a funnel having a long neck, the long end being inserted nearly to the bottom of the cell. When fresh solution is poured in, the spent liquor will run out of the lip into the gutter.

Immediately after a series of experiments, the battery must be emptied, and the plates well cleaned by dashing water between the cells. If this be not immediately attended to, it will be exceedingly difficult to remove the deposit from the cells. A Cruikshank's battery is best cleaned by laying it on its side.—*London and Edinburgh Philosophical Magazine*, *vol.* x. *p.* 244.

I am happy to be able to adduce my testimony in favour of this form of battery, it is in my opinion, one of the most valuable additions to our stock of philosophical apparatus, and will I do not doubt soon supersede the *acid charged battery* altogether. I have found its effects to be equally energetic with those of the Wollaston battery of equal surface, at the first moment of immersion, as stated by De la Rue, and what is of by far the most importance, *permanent* in its action. The rationale of its action is also extremely beautiful, and I cannot too strongly recommend it to the notice of my readers.

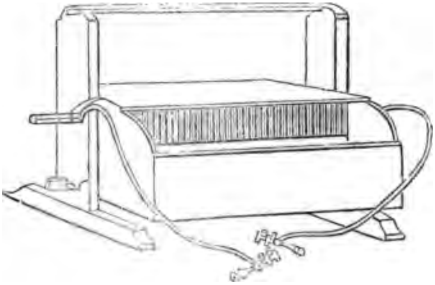
I shall now describe the arrangement of Professor Hare, of Philadelphia, which he was so obliging as to show and describe to me at the meeting of the British Scientific Association at Bristol, in 1836. This instrument combines the advantages of the *compound* trough, and the calorimotor, or deflagrator. It is represented in *Fig.* 31. A voltaic series fixed in a trough is combined with another trough destitute of plates, and of a capacity sufficient to hold all the acid necessary for an ample charge. The trough containing the series is joined to the other lengthwise, edge to edge, so that when the sides of the one are vertical, those of the other must be horizontal. The advantage of this is, that by a partial revolution of the two troughs, thus united, upon pivots which support them at the ends, any fluid which may be in one trough must flow into the other, and reversing the movement must flow back again. The galvanic series being placed in one of the troughs, and the acid in the other, by a movement, such as has been described, the plates may all be instantaneously subjected to the acid, or removed from it. The pivots are made of iron, coated with brass or copper as less liable to oxidizment. A metallic communication is made between the coating of the pivots, and the galvanic series within. In order to

Fig. 31.



produce a connexion between one recipient of this description and another, it is only necessary to allow a pivot of each trough to revolve on one of the two ends of a strap of sheet copper. To connect with the termination of the series, the leaden rod to which are soldered the vices, or spring forceps, for holding the substances to be exposed to the deflagrating power, one end of each of the leaden rods is soldered to a piece of sheet copper. The pieces of copper thus soldered to the leaden rods, are then to be placed under the pivots, which are of course to be connected with the termination of the series. The last mentioned connection is conveniently made by means of straps of copper severally soldered to the pivots and the poles of the series, and screwed together by a hand vice. Each pair consists of a copper and zinc plate soldered together at the upper edge, where the copper is made to embrace the edge of the zinc. The three remaining edges are made to enter a groove in the wood, being secured therein by cement. For each inch in the length of the trough there are three pairs. In the series represented by *Fig.* 31, there are seven hundred pairs of seven inches by three. And in that represented by *Fig.* 32, one hundred pairs of fourteen

*Fig.*32



inches by eight. The latter will deflagrate wires too large to be ignited by the other, but is less powerful in producing a jet of flame between two charcoal points, or in giving a shock.

A modification of Dr. Hare's battery is described by Mr. J. Young, chemical assistant in the Andersonian university, in the 10th volume and 242nd page of the London and Edinburgh Philosophical Magazine. It possesses all the advantages of approximation of the plates and compactness of Dr. Hare's battery; and an equal effect is produced with *half* the quantity of sheet copper, which arises from both sides of the copper plates being presented to surfaces of zinc.

The sheet copper and sheet zinc to be used, are first cut into long ribbons, of the breadth which it is intended to give the plates. Suppose the ribbons two inches broad: both the copper and zinc ribbons are then divided into lengths of five inches, and a portion cut out as in *Fig.* 33. The slip is thus divided into two squares of two inches each, which are connected at A, and a piece is left projecting at B. The zinc and copper sheets are cut up exactly in the same way. *Fig.* 34 represents therefore either a single zinc or a single copper plate. The plate is then bent at A, and presents the appearance represented in the figure.

Fig. 33.

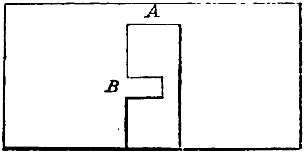
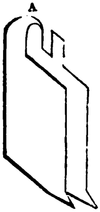


Fig. 34.



In *Fig.* 35 we have two plates, one of copper, C, and the other of zinc, Z, which are exactly alike in construction, but placed differently, as shown in the figure. Thin projecting parts, B B, are soldered together, and this is the only metallic communication between them that is allowed to exist. *Fig.* 35 therefore, is only one copper and one zinc plate, or it is one pair of plates. Each pair is made up in the same way. In arranging a number of pairs to form a battery, they are interlaced, so that a copper square comes in between each couple of zinc squares, and a zinc square between each couple of copper squares. It is easy to see how this arrangement can be made, when the plates are in the hand, though it is difficult to describe it. At the positive end of the battery there is a single copper plate, which is soldered at the top to the last double copper plate, as seen in *Fig.* 36, which figure represents three pairs properly arranged and also the manner in which they should be fitted up, and kept steadily apart in a wooden frame. This frame consists of two cross bars, EE, EE, in front and the same behind, dove-tailed into solid ends. The channels in the cross bars for the reception of the edges of the plates, are formed by placing four cross bars together, and sawing a little way into one side of them all, every eighth of an inch or so in their length, so as to form a set of parallel grooves. We have by means

Fig. 35.

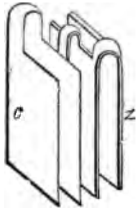
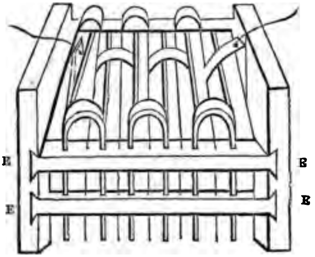


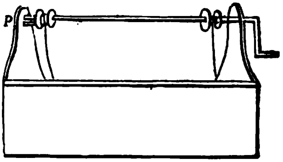
Fig. 36.



of this frame a much greater security that no metallic contact will occur between contiguous plates, than when they are separated by wedges of cork, as in Dr. Hare's construction, which may slip out.

The frame and plates are introduced into a trough which may be of wood or stoneware, containing the exciting liquor. Dr. Hare's revolving arrangement of the two connected troughs, may be adopted for this battery, although the inventor has been led to give a preference in practice to a single trough to contain the frame. To the solid ends of the frame are attached two cords which are fixed to two pulleys, on which they are wound up on turning a winch, as represented in *Fig.* 37, by which means the frame and battery can be raised out of the liquid. If the axis on which these pulleys are fixed, can be moved a little backwards and forwards on its bearings, it is easy by means of a little projecting peg at P, which fits into a hole in the side of the pulley, to fix and support the frame in a position above the trough, and out of the exciting fluid, when that is desirable. But the form of the trough to contain the frame and plates may be varied according to the object in view, or to the purposes to which the battery is to be applied.

Fig. 37.



In comparing a battery of the form here described, either with Dr. Hare's, or any of the other forms in use, it is to be remembered that the plates or elements of the battery are all of double the size they appear to be; or that in this construction you have half the number of pairs, but each of double the dimensions of a pair in any of the old batteries having the same appearance.

A small battery of this construction containing twelve pairs of two inches breadth of plates, (the size which we have taken above as an example) may be contained in a trough eight inches in length, and will evolve, when its terminal wires are soldered to a Faraday's volta-electrometer, (an instrument to be described in the next lecture,) six or seven cubic inches of oxygen and hydrogen, mixed in three or four minutes, with a charge of half an ounce of sulphuric acid and half an ounce of nitric acid, in twenty-four ounces of water, fluid measure, and is therefore amply sufficient to demonstrate the decomposition of water on a considerable scale.

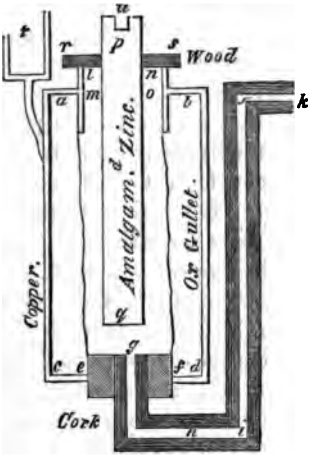
It is proper to use the thickest sheet zinc which can be had, in the construction of the plates, although the thinnest sheet copper will suffice, from its being so well supported. When the zinc plates are worn out, the cross bars may easily be pulled out of the solid ends, and the elements of the battery separated. New zinc plates being soldered to the old copper, the whole may be again quickly re-arranged in the old frames.

But by far the most useful voltaic arrangement that has lately been devised, is that of Professor Daniell, and is called the "*constant battery*," from the regularity and duration of its action, which render it applicable to the determination of many important questions, which have hitherto been perplexed with the variable conditions of the voltaic current.

In a series of papers in the Philosophical Transactions for 1836, the author describes these batteries, and the circumstances which led to their adoption. It has been remarked in the former part of this lecture that the evolution of hydrogen gas from the negative metallic surface in the common galvanic battery, greatly interferes with the development of *available* electricity, for, that a considerable portion of the electricity that is actually generated, is probably spent in giving a gaseous form to the hydrogen of the decomposed water. But besides this, Mr. Daniell found that not only were the oxides of copper and mercury reduced by the *nascent* hydrogen, at the moment of its formation, when salts of these metals were purposely dissolved in the fluid of the cells of the battery; but the oxide of zinc itself formed at the generating plates, *was reduced* at the conducting plates, which became ultimately so incrusted with metallic zinc, as entirely to destroy the circulating force. The variations and progressive decline of the power of the ordinary voltaic battery, are thus accounted for, since the transfer of the electro-positive metal, must eventually cause two zinc surfaces to become opposed to each other, the use therefore of the nitric acid in the battery charge is to remove the hydrogen by combination. Since therefore the hydrogen has a two-fold injurious tendency, its absence altogether becomes a desirable object to effect. In the battery constructed by Mr. Warren De la Rue, this is done by the employment of sulphate of copper as the exciting agent, and in the arrangement of Professor Daniell, the same is accomplished, but under circumstances rather different, as will presently appear.

Fig. 38 represents a section of one of the cells of Daniell's "sustaining" or "constant" battery; *a b c d* is a cylinder of copper, six inches high and three and

Fig. 38.



a half inches wide; it is open at the top *a b*, but closed at the bottom, except a collar *e f*, one inch and a half wide, intended for the reception of a cork, into which a glass syphon tube *g h i j k* is fitted. On the top *a b*, a copper collar corresponding with the one at bottom, rests by two horizontal arms. Previously to fixing the cork syphon tube in its place, a membranous tube, formed of part of the gullet of an ox, is drawn through the lower collar *e f*, and fastened with twine to the upper, *l m n o*, and when tightly fixed by the cork below, forming an internal cavity to the cell communicating with the syphon tube, in such a way, as that, when filled with any liquid to the level *m o*, any addition causes it to flow out at the aperture *k*. In this state, for any number of drops allowed to fall into the top of the cavity, an equal number are discharged from the bottom *a*, at the top of the zinc rod. Various connexions of the copper and zinc of the different cells, may be made by means of wires proceeding from one to the other. In the construction of this battery, Mr. Daniell has availed himself of the power of reducing the surface of the generating plates to a minimum. The effective surface of one of the amalgamated zinc rods, being less than ten square inches, whilst the internal surface of the copper cylinder to which it is opposed, is nearly seventy-two inches. His principal objects have been to remove out of the circuit the oxide of zinc, which has been proved to be so injurious to the action of the common battery, as fast as the solution is formed, and to absorb the hydrogen evolved upon the copper, without the precipitation of any substance that might deteriorate the latter.

The first is completely effected by the suspension of the zinc rod in the interior membranous cell, into which the fresh acidulated water is allowed slowly to drop, from a funnel suspended over it, and the aperture of which is adjusted for the purpose; whilst the heavier solution of the oxide is withdrawn from the bottom at an equal rate by the syphon tube. When both the exterior and interior cavities of the cell were charged with the same diluted acid, and connection made between the zinc and the copper, by means of a fine platinum wire one five hundredth of an inch in diameter, he found that the wire became red hot, and that the wet membrane presented no obstruction to the passage of the current.

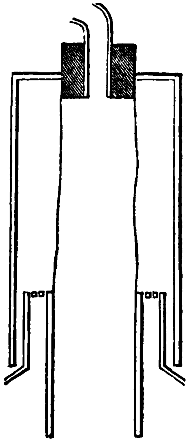
The second object is obtained by charging the exterior space surrounding the membrane, with a saturated solution of sulphate of copper, instead of diluted acid; upon completing the circuit the current passed freely through this solution; no hydrogen made its appearance on the conducting plate, but a beautiful pink coating of pure copper was deposited upon it, and thus perpetually renewed its surface.

When the whole battery was properly arranged and charged in this manner, no evolution of gas took place from the generating or conducting plates, either before or after the connexions were complete; but when a voltameter was included in the circuit, its action was found to be very energetic. It was also much more steady and permanent than that of the ordinary battery, but still there was a gradual but very slow decline, which Mr. Daniell traced at length to the weakening of the saline solution, by the precipitation of the copper, and consequent decline of its conducting power.

To obviate this defect, some solid sulphate of copper was suspended in muslin bags, which just dipped below the surface of the solution in the cylinders, which gradually dissolving as the precipitation proceeded, kept it in a state of saturation. This expedient fully answered the purpose, and Mr. Daniell found the current perfectly steady for six hours together. This arrangement he has since improved, by placing the salt in a perforated colander of copper, fixed to the copper collar.

Fig. 39 represents a section of this additional arrangement. The colander with its central collar, rests by a small ledge upon the rim of the cylinder. The membrane is drawn through the collar, and turning over its edge is fastened with twine. After this alteration, the effective length of the zinc rods exposed to the action of the acid, was found to be no more than four inches and a quarter.—*Philosophical Transactions for* 1836.

Fig. 39.



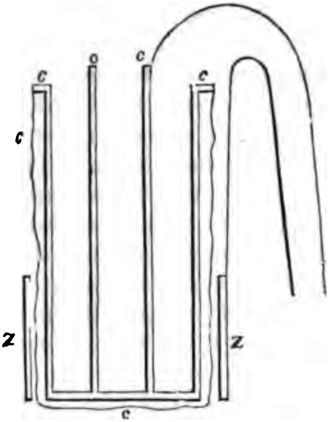
The advantages of this battery over those of the ordinary construction are very great; it secures a total absence of any wear in the copper; it requires no nitric acid, but the substitution of materials of great cheapness, namely, sulphate of copper, and oil of vitriol; it enables us to get rid of all local action, by the facility it affords of applying amalgamated zinc, and allows the replacement of zinc rods at a very trifling expence; it secures the total absence of any annoying fumes; and, lastly, it produces a perfectly equal and steady ourrent of electricity for many hours together.

With a battery of twenty cells arranged in a single series, twelve cubic inches of mixed oxygen and hydrogen gases may be collected from a voltameter in every five minutes of action, and when they are first connected in pairs, and afterwards, in a series of ten, the quantity amounts to seventeen cubic inches. Eight inches of platina wire, one two-hundredth of an inch in diameter, may be kept permanently red hot by the same arrangement, and the spark between charcoal points is very large and brilliant.

Mr. Daniell has even made it the source of the purest oxygen for laboratory purposes. To this end he has constructed an *oxygen cell*, by substituting a plate of platina, for the rod of zinc, enclosing it in the membranous tube, which is closed at the upper end by a glass tube, bent in a proper form to deliver the disengaged gas, under a receiver. In this arrangement the hydrogen is absorbed as before, by the oxide of copper, but the oxygen to the amount of eighty cubic inches per hour, is given off from the platina.

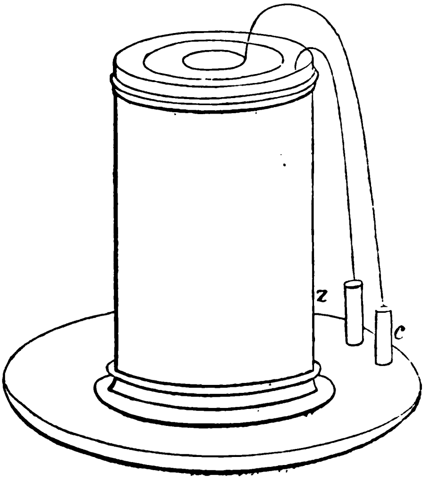
T. W. Mullins, Esq. M..P, has introduced another very useful form of constant battery; it is shown in section, in *Fig*. 40, and in perspective, in *Fig*. 41.

Fig. 40.



In an earthenware pot six inches deep, and four wide, is placed a cylinder of amalgamated zinc, standing on

Fig. 41.



three legs half an inch long, cut out of the cylinder, the depth of which, including the legs, is only two inches; within this cylinder, and at three eighths of an inch distant, stands a copper vessel having a rim a quarter of an inch wide, surrounding its outer edge, round which a thin clear bladder is tied; the bottom of the vessel rests on a circular piece of baked box wood, which projects one fourth of an inch beyond the cylinder; the bladder well cleaned and moistened, is drawn all over and fastened round the upper rim by a string, the wood at the bottom preventing it from contact with the copper, which would otherwise injure the membrane. This cylinder which is the depth of the pot, is pierced with six holes equidistant from the top and bottom, which communicate with an inner cylinder, separated from the outside one by a space of three fourths of an inch, the bottom being on a level with the lower edge of the holes and soldered to the larger cylinder. This chamber is intended to hold crystals of sulphate of copper, when required, and to receive the solution, which should not rise higher than the upper edges of the holes. A small quantity of muriate of ammonia, (sal ammoniac) in the proportion of five parts of the saturated solution, to one hundred of water, is to be poured *outside* the membrane, until it rises to the upper edge of the zinc; the latter solution does not require renewal, the former will require the addition of a few crystals of the sulphate every four hours. The connexions are made by strips of copper, which are soldered to the zinc and inside copper cylinder, and which bend over the edge of the jar, and enter two cups holding mercury, from which the wires for transmitting the electrical current through any apparatus may proceed, or by fastening the mercury cups *directly* on wires soldered to the two metals.

This battery continues active as long as a particle of metallic salt remains in solution, for if to the nearly exhausted and colourless solution, you add about six drops of the saturated salt, the original power of the battery is instantly restored, and continues for some time. In order to keep up then a varying current, it is only necessary to keep a few crystals of sulphate of copper on the shelf, which will be gradually dissolved, and carried in solution to the external surface of the copper.

Mr. Mullins has constructed a somewhat different form of battery for intensity effects. "I have first," he says, "as in the quantity battery, a shallow cylinder of zinc within, and close to the internal surface of the earthenware pot next the copper cylinder as before; but instead of letting the inside of this cylinder go for nothing, the internal surface of the copper is lined with very thin caoutchouc for insulation; then comes another small cylinder of zinc, then a copper one lined as the last, then a zinc, and lastly a copper, each copper of course enveloped in membrane. This battery is one of extraordinary power in decomposition and other effects of intensity, which in my opinion depends upon a new principle, which is developed in this mode of construction and arrangement, that is, the *restricting* the electric current to gradually *diminishing metallic surfaces* as it advances, so that, as the quantity accumulates, the conducting surfaces are *reduced*, and of course a much higher degree of intensity is a necessary consequence."

In Sturgeon's "Annals of Electricity," for April, 1837, page 224, there is the following account of a sustaining battery of great power compared with its size, by the Rev. John Shillibeer. It is represented in *Fig.* 42.

Fig. 42.

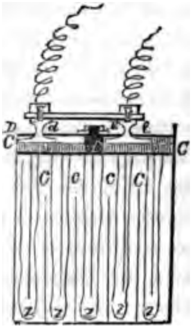
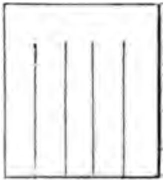


Fig. 43.



"Finding on trial that a single piece of zinc, (surface three inches) surrounded by a membrane, when placed in a copper vessel containing a solution of sulphate of copper, could be soon erected, and that a rotatory motion might be kept up during pleasure, I formed the apparatus about to be described, which consists of a well made copper trough, about three inches deep, and two and a quarter wide, divided into compartments according to the number of zinc plates employed. *Fig.* 43 represents a section of the copper trough. The plates are soldered firmly to a copper bar, and by the aid of a screw are fastened to a piece of hard wood, answering for a cover to the trough, which with the zinc plates and movement for directing the course of the electric fluid, may be seen by reference to *Fig.* 42. In a groove cut out of the cover on each side the screw, is fitted a copper slide; and these slides are joined by an elbow, to a piece of ivory forming a handle, by which, passing immediately over the screw, each wing of the slide may be brought readily into contact with the copper or zinc.

" The use of this movement or pole director, I will endeavour to make apparent.

"In *Fig.* 42 let AA represent a section of the wood cover with a groove for the slide to stand in, B the screw in connection with the zinc, CC, the opposite sides of the copper trough Dd Ee, the two wings of the slide. Now let the wing Dd be in contact with C, and Ee with B; it is evident that the stream of electricity is going out from the wire in connection with the wing Dd, and is returning by the wire appended to the wing Ee, into the zinc plates *via* B. Shift the slide so that Ee be in contact with C, and Dd with B, the stream will be reversed, making its exit by Ee, and returning by Dd to the zinc, *via* B. The zinc plates should be covered tightly with a membrane, so as to prevent any possible precipitation of sulphate of copper upon them. When used for sustaining a weight, the membrane should be slipped off, and instead of sulphate of copper, diluted nitrous acid should be used."

I shall lastly quote from the same publication a description of a very simple and easily constructed battery by Mr. Bachhoffner, (page 214.)

"A piece of thin sheet copper is coiled up into the form of a cylinder, and retained in that position by a fine copper wire. The size I usually employ is that of four inches by two and a half; it is then to be placed in a small bladder, which is secured round the copper by packthread, the top being left open, and the membrane forming the bottom of the cylinder; a piece of zinc is rolled up in a similar manner, a copper wire having been previously soldered to each zinc and copper plate, to form the connexion. The battery may be placed in a jelly pot. To excite it, pour into the copper cylinder a saturated solution of sulphate of *copper; outside* of the copper, and in contact with the zinc, must be placed another solution; it matters little of what nature, one of common salt I find to be as good as any that I have tried, and it has the advantage of being cheap and always at hand. If the battery is required to be kept in action for two or three days, a few crystals of sulphate of copper must be added to the solution in contact with the copper."

The value of the "constant" battery as an addition to our stock of philosophical apparatus, will be seen and appreciated more fully in the seventh and eighth lectures, when we shall be on the subject of electro-magnetism. I must now direct your attention to the effects of galvanic electricity, and this shall form the subject of the next lecture.

LECTURE IV.

ON GALVANISM.

FROM what was said in the last lecture, it will be evident to all of you, that there are *three* principal circumstances in which the electricity produced by the voltaic battery, differs from that obtained from the common electrical machine. *First*, the very low state of intensity in which it exists in the former, when compared with the latter; *secondly*, the large quantity of electricity that is set in motion in the voltaic battery; and, *thirdly*, the continuity of the current, and its perpetual reproduction, even when the uniting wire is continually tending to restore the equilibrium.

The effects of a highly charged electrical battery while its action lasts, are very striking and energetic, reminding the experimentalist of the destructive operation of lightning, but like that awful natural agent, its power is momentary, and beyond the reach of human skill to regulate or controul, while the changes it produces on bodies are violent and sudden. Not so the galvanic battery. What is deficient in *intensity* in this instrument, is compensated for by the immensity of the *quantity* which it develops, and the perpetual *and undiminished* stream in which it circulates. Faraday has asserted on the strongest evidence that the quantity of electricity employed by the galvanic battery in decomposing a single grain of water, is equal to that of a powerful flash of lightning; hence may be conceived the advantages which have accrued to science, from the acquisition of so powerful an instrument of analysis. Since its introduction, chemistry has advanced with gigantic strides; for bodies which have resisted every other means that have been used to effect their decomposition, have yielded to galvanism. It was with the voltaic battery that Sir H. Davy discovered the metallic bases of the alcalies and earths, proving potash, soda, lime, barytes, strontia, &c., to belong to the same class of bodies as red lead, or oxyd of manganese.

In considering on the present occasion the effects of galvanism, it will be convenient to do so, in relation to the three circumstances mentioned above, as contrasting it with ordinary electricity. It has been shown in a former lecture, that a piece of glass or sealing-wax rubbed with silk or flannel, and held near the cap of the gold-leaf electrometer, causes an immediate divergence in the leaves; but the largest calorimotor that has ever been constructed, is incapable of producing an equal effect. By means of a delicate condenser, it is indeed possible to obtain indications of electricity, but it is even then scarcely appreciable. With a battery of many pairs the effect is very distinct, though never powerful, and it matters not what the size of the plates may be, pairs of copper and zinc one quarter of an inch square, are just as effectual as large ones; numerous alternations being the only requisite; hence we see the difference between compound and simple voltaic arrangements, and between intensity and quantity. From the largest calorimotor or single circle that was ever constructed, no shock can be obtained, nor the slightest electro-chemical effect exhibited; but a few ounces of zinc and copper arranged in thirty or forty pairs, and excited by the same acid, will diverge gold leaves, decompose water, and give a distinct shock; indeed, the effects of thirty or forty pairs of plates two inches square, will be quite as energetic upon bad or imperfect conductors, as the same number of plates twelve inches square; they will decompose water equally rapid, and will give equally powerful shocks; but on good conductors, the effects of large plates will be very distinct, the spark and light from charcoal terminal points will be much more intense, because quantity as well as intensity is required, the former of which is furnished by the superior surface of the larger arrangement.

A Leyden phial or electrical battery, may be charged by a compound voltaic battery, from either wire of the unbroken circuit, provided the battery be in a state to supply a large quantity of electricity of high tension, as when formed of numerous four-inch plates excited by diluted acids; and the charge communicated to the jars, will be equal in intensity to that of the electricity developed by the voltaic battery.

On bringing the terminal wires of such a battery near each other, a spark is observed to pass between them, and on establishing a communication by means of the hands, previously moistened, a distinct shock is felt; on sending the current through fine metallic wires, or through pieces of compact charcoal, the wires *of the* most refractory metals are fused, and a vivid white light appears at the points of the charcoal, equal, if not superior in intensity to that emitted during the burning of phosphorus in oxygen gas. Now this latter effect has nothing whatever to do with combustion, which is proved by the fact that the light is produced equally brilliant, in vacuo, or in an atmosphere containing no oxygen, and more satisfactorily if possible, from the circumstance that the charcoal is not in the least altered by the operation, and that it even takes place under water. If the communication be established by metallic leaves, the metals burn with vivid scintillations; gold leaf burns with a white light tinged with blue, yielding a dark brown oxyd; the light emitted by silver is exceedingly brilliant, and of an emerald green colour; copper emits a blueish white light, attended by red sparks; lead a beautiful purple light; and zinc a brilliant white light, inclining to blue, and fringed with red.

The only method apparently of explaining these appearances is, by supposing that the current passes with difficulty along the metals, a circumstance which, as they are perfect conductors, can only happen when the quantity to be transmitted is out of proportion to the extent of surface over which it has to pass. For these experiments therefore, it is better to employ *few* plates of very large size, and a strong acid, the object being energetic action of a short continuance.

But it is the chemical effects of galvanism that convey to the mind the strongest impressions of its mysterious and wonderful agency. Unlike its power of eliciting heat, it is manifested, not while it is traversing bodies of good conducting power, but on the contrary, when it meets with impediments in its passage; this property of the voltaic pile was discovered and described by Messrs. Nicholson and Carlisle, in the year 1800. Water was the first substance decomposed. In 1807, Davy communicated to the Royal Society, his celebrated lecture, "on some chemical agencies of electricity," in which the electro-chemical powers of the pile were elaborately examined, and which formed the ground work of the brilliant discoveries to which he was soon afterwards led, by the prosecution and extension of his researches. Many important phenomena, however, connected more particularly with the development of electricity by chemical action, have recently engaged the attention of Professor Faraday, and in his "Experimental Researches," published in 1832, 1833, 1834, and 1835, he has not only explained and enlightened much that was before unintelligible, but has stamped a new character on electrical, as connected with chemical science. In point of originality of talent, and perspicuity, these celebrated essays rank among the first efforts of philosophy of the age, if, indeed, they do not surpass all others.

When water or any saline solutions are made part of the electric circuit, so that a current of electricity may pass through them, they are decomposed, that is, they yield up their elements in obedience to certain laws. Water is resolved into oxygen and hydrogen gases, and the acid and alkaline matter of the neutral salts, which it holds in solution, are separated, *not* in an indiscriminate manner, but the oxygen and acids are always developed at the *anode*, or the surface by which the electricity enters the *electrolyte*, that is, at the termination of the wire, proceeding from the zinc end of the compound battery, which is positive,* and the hydrogen and alkaline bases are given off at the *cathode*, or surface by which the electric current leaves the body under decomposition, and which corresponds to the termination of the wire proceeding from the terminal copper plate, which is negative.

But these terms *anode* and *cathode* require explanation. The terminations of the wires connected with the opposite ends of a voltaic battery, are commonly designated its positive and negative *poles;* the idea being, that they have certain attractive or repulsive energies, which they exert towards the elements of the decomposing liquid, just as the poles of a magnet act towards iron. Now Faraday denies the existence of this force, and maintains that the poles as they are called, act simply as a path or door to the current, he hence proposes for them the term *electrodes*, from ηλεκτρον and οδος a way, meaning thereby, *the substance*

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* In the simple circle, the copper is represented as being the positive end; whereas in the compound circle the same term is applied to the zinc extremity ; but on examination, it will be found that the actual direction of the current is the same in both cases ; but in the simple circle, the conducting wire communicates with the metal *in direct contact with the exciting liquor*, while in the compound circle, it is connected *not* with the plate necessarily immersed, but with that associated with it, and therefore of a different kind. The compound circle reduced to its most simple condition, will be represented thus :—copper—zinc—fluid—copper—zinc—here the copper is negative, and the zinc positive, but as they neither of them touch the fluid, they act merely as conductors for the accumulation on the contiguous plates ; they are *not* concerned in the effect, and may therefore be removed, and the arrangement brought to the state of a simple circle, thus :—zinc—fluid—copper —where the zinc is negative, and the copper positive.

or surface, whether of air, water, metal, or any other substance, which serves to convey an electric current into, and from the decomposing matter, and which bounds its extent in that direction. The surfaces of this liquid, or the places at which the electric current enters, and goes out from the electrolyte, he terms *anode* and *cathode*, from *ανα* upwards, and *οδος* the way in which the sun rises, and *κατα* downwards, the way in which the sun sets, supposing the electricity to follow the passage of the sun, that is, to pass from east to west. If for instance, we suppose a current of electricity traversing a wire in the direction of the darts in the diagram,

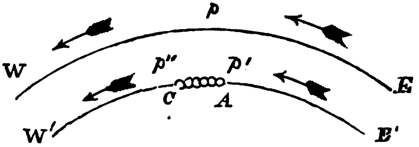


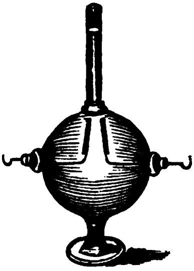
Fig.44.

and entering at E, then on separating the wire at p, $p'p''$ would become its electrodes; p' would be the anelectrode or emitting electrode, and p'' the cathelectrode or receiving electrode; E′ being the wire connected with the zinc, and W the wire connected with the copper end of the compound battery; and if we suppose the chain of small circles to represent the fluid under decomposition, A will be its anode, and C its cathode.

To electrolyze a compound, is to decompose it by the direct action of galvanism, its name being formed from *ελεκτδον* and *λυω* to inclose or set free; and an *electrolyte* is a compound, which may be electrolyzed. The elements of an electrolyte, Faraday calls ïons, from *ιον* going, neuter participle of the verb to go. *Anions* are the ïons which appear at the *anode*, and are usually termed the electro-negative elements of a compound, such as oxygen, chlorine, and the acids; and the electro-positive, substances such as hydrogen, metals, alcalies, which appear at the cathode, are called *cations*. Different opinions may be entertained as to the use of some of these terms; there can however be no objection to the words, electrode, electrolyze, and electrolyte, and indeed they are peculiarly applicable.

An exact uniformity in the circumstances attending these decompositions is observed, and it has been hence inferred, that the natural electricity of the elements, is the antagonist of that supposed to belong to the surfaces at which they appear, in conformity with the general law, "that bodies similarly electrified repel, but, dissimilarly, attract each other." Moreover, that if the electro-chemical forces by which the elements of bodies are united, are stronger than those of the battery to which they are subjected, they will resist decomposition; and that substances, which in their ordinary state, evince no disposition to enter into combination, may be made to do so, by communicating to them oppositely electrical states. Faraday has proved that contrary to the general opinion all compounds are *not directly* decomposable by voltaic electricity, but in this assertion, it is necessary to distinguish between primary and secondary decomposition. Water and hydro-chloric acid are electrolytes, for either of these fluids confined in a glass tube sealed at one extremity, and made part of the electrical circuit by means of gold or platina wires, hermetically secured in the top of the tube, or arranged as in *Fig.* 45, and about a quarter of an inch apart, will be speedily resolved into its ele-

Fig. 45.



ments; from the water, oxygen gas will be developed at the anelectrode, and hydrogen in twice the quantity will escape at the cathelectrode. When the tube is about half full of these mixed gases, if a spark from an electrical machine be passed between the wires, an explosion will take place, and if care be taken to prevent any escape, by the expansion, the tube will be refilled with water, that fluid having been reproduced by the explosion.* This experiment is very important, as establishing the composition of water, for if the volumes of the gases are reduced to their respective *weights*, we shall find that the volume of hydrogen being one, that of oxygen (one half the quantity) will be eight, showing that nine parts of water consist of eight parts of oxygen, and one of hydrogen, and that the latter gas is sixteen times lighter than the former. Another conclusion has been drawn from the decomposition of water. It has been shown that bodies which are similarly electrified mutually repel, and bodies in oppositely electrical states mutually attract each other; now as oxygen is attracted by the positive wire, it must possess the opposite or negative state, and as hydrogen is attracted by the negative wire, its own inherent electrical state must be positive. Hydrogen, therefore, and all substances passing to the same side of the battery, are denominated *electro-positive bodies*, and oxygen with all substances that take an opposite direction, are called *electro-negative bodies.*

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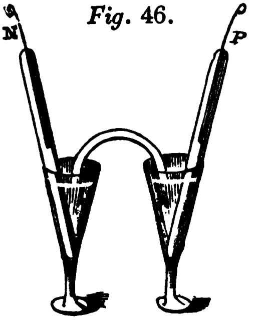
* If a small quantity of sulphuric acid be added to the water, its conducting power will be much improved; the decomposition will, *consequently*, proceed more rapidly, and by a lower power.

If, in this experiment, instead of employing pure water, we electrize a portion containing saline matter, as for instance, hard pump-water, we shall find that the *saline ingredients* will become decomposed, and their elements given up in obedience to certain laws.

Take a syphon shaped tube, and placing its bent part in a wine glass for support, fill it with the blue infusion of red cabbage; then put a few crystals of some known salt, such as sulphate of soda, into the tube, and electrize the solution; in a short time, the liquid nearest the negative side of the battery, will become green, indicating the presence of an alkali, and the liquid in the positive side of the tube, will become *red,* showing that an acid is present; reverse the direction of the current, and the colours will also be gradually reversed. Thus sulphate of soda has been resolved into sulphuric acid and soda, and the acid ranks with oxygen in its electrical relations, and the soda with hydrogen. The same is the case with every other neutral salt, the acid being invariably thrown off at the anode, and the base at the cathode.

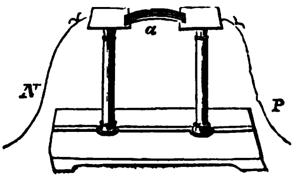
Fig. 46.



If we take two glasses, filled with the blue infusion, holding in solution sulphate of soda, and immerse in each an inverted glass tube, in which two platina wires are fixed, and then connect the two by a glass syphon, on electrizing the solution, it will be found that notwithstanding they are in separate vessels, the blue liquor will as before be turned red and green, and if the experiment be continued sufficiently long, the alkali of the salt will have passed from P to N, and the acid from N to P; the acid and alkali appearing to traverse the connecting syphon in opposite directions: it was hence inferred, that *under the influence of electrical attraction, the usual chemical affinities are suspended*, but Faraday has proved that there is in reality no such thing as a transfer of ïons, in the sense usually understood. In order that the elements of decomposed water should appear at the opposite electrodes, there must be water between them; and for the similar separation of sulphuric acid and soda, there must be a line of particles of sulphate of soda extending from one electrode to another. Thus if water be carefully poured on a solution of sulphate of magnesia, platina conductors may be so introduced and arranged as to make the saline solution the anelectrode, and the water the cathelectrode; in this case, a deposit of magnesia occurs at the *line of contact* between the water and the solution, and none reaches the negative pole. So in the case just mentioned, where sulphuric acid and soda appeared to quit and pass each other, there must have been by capillary attraction an actual transfer of the salt before decomposition occurred.

The same is probably the case in the decomposition of sulphate of baryta, which may be effected in the following manner: provide two insulated discs of platina, as in *Fig.* 47, one of which is *to be put into* communi-

Fig. 47.



cation with the negative, and the other with the positive end of the pile; place upon each of these a few grains of finely powdered sulphate of baryta, moistened by a drop or two of water, and connect the discs, which should be within half an inch of each other by some filaments of wet cotton; in a few minutes baryta will appear to test papers at the negative disc, and sulphuric acid at the positive.

The following curious experiment was also made by Davy, in support of his idea, that one substance might be electrically attracted through another, possessing a strong chemical attraction for it. Three small platinum trays, about an inch square, were placed side by side, and connected with each other by shreds of well soaked cotton; care was taken to keep them upon a level. The exterior trays were then filled with a solution of sulphate of soda, and rendered negative and positive; and the central one with *solution of ammonia,* which has a strong attraction for sulphuric acid. It was found after some hours electrization, that a portion of the sulphuric acid of the salt, had passed from the negative to the positive vessel, and apparently therefore, had traversed the ammoniacal solution, but had not there stopped in combination, as would have been the case, had the substances *not* been under electrical influence. But according to Faraday, who adopts the opinion of Grotthuss, the decomposing influence is not exerted *on any single particle* of the electrolyte, but that rows of particles lying between the electrodes, are equally subject to its action. When a particle of oxygen is evolved at the positive electrode, the hydrogen with which it has been combined, is not *transferred at once to the opposite electrode*, but unites with the oxygen of a contiguous particle of water on the side towards which the positive current is moving; the second particle of hydrogen decomposes a portion of water still nearer to the negative electrode, and the same process of decomposition and reproduction of water continues until it reaches the water in immediate contact with the negative electrode, the hydrogen of which is disengaged. This operation takes place at both electrodes, precisely at the same moment. A row of particles of oxygen suddenly lose their affinity, for the hydrogen situated on the side next the negative electrode, in favour of those respectively adjacent to each on the other side, while the affinity of a similar row of particles of hydrogen is diminished for the oxygen on the side of the positive electrode, and is increased for those on their opposite side; hence it appears indispensably requisite to voltaic decomposition that the electrolyte should itself occupy the space between the electrodes, and be in contact with them; and hence in Davy's experiments, there is no transfer of sulphuric acid through the ammonia, there being through that fluid, a line of particles of sulphate of soda, through which the electrical current is passing and with which it is alone concerned. It is not however evident in this theory, *why* there should be such a disturbed order of affinities in the elements of an electrolyte.

No substance can be decomposed by galvanism, unless it is a conductor of electricity, and consequently no substance *not* an electrolyte, can serve to excite a voltaic battery. Nevertheless, electricity of a very feeble tension, may pass through an electrolyte without effecting its decomposition, but in such cases the decomposition ensues when the conducting power of the electrolyte is improved, or the intensity of the electricity increased. If, for instance, a solution of sulphate of soda be made a part of a circuit transmitting electricity of very low intensity, the galvanometer* in such a circuit will be deflected, so as to demonstrate the passage of electricity, but no appreciable decomposition of the salt will ensue; on increasing the *intensity* of the current, the deflection of the magnetic needle is not inincreased, but the acid and alkali of the salt are separated.

There is a considerable difference in the resistance offered by different chemical compounds, to electrochemical decomposition; some substances giving up their elements to currents of much lower intensity than others; iodide of potassium requires a very feeble current; fused chloride of silver comes next; then fused protochloride of tin; fused chloride of lead; fused iodide of lead; solution of hydrochloric acid; and then water acidulated with sulphuric acid. Faraday has also shown that the chemical power is in direct proportion to the *absolute quantity* of electricity which passes, however much other circumstances, such as the size of electrodes, and conducting wires, number and size of plates, and nature of the exciting fluid may vary.

When in a voltaic battery there is no zinc oxidized, *but what contributes to excite an electric current, and the circulating electricity is to be referred solely to this process*, there is a certain ratio observable between the quantity of metal dissolved, and the hydrogen set free not only from the corresponding copper plate, but also from the negative electrode. Analysis shows that water is composed of eight parts by weight of oxygen, and one of hydrogen, and that oxide of zinc consists of thirty-two of zinc, and eight of oxygen. Now it is found that thirty-two parts of zinc must be dissolved during the evolution of one part of hydrogen gas, and the same quantity of electricity set in motion by that oxidation if sent through fused chloride of silver, and iodide of lead, so as to decompose these salts, will evolve thirty-six of chlorine, and one hundred and twenty-five of iodine at the *anodes*, and one hundred and eight of silver, and one hundred and four of lead at the *cathodes*, and these numbers are the exact *chemical equivalents* or combining proportions of the respective elements. Similar facts have been ascertained of other compounds verifying a new and important discovery, namely, that electro-chemical decomposition is perfectly definite; a given quantity of electricity evolving the ingredients of compound bodies in well defined and invariable proportions, to which Faraday has given the name of *electro-chemical eqvivalents.* This being distinctly proved, if a portion of water be placed any where in the electric circuit, the quantity of oxygen and hydrogen which is evolved from it will furnish a *measure* or mode of expressing the quantity of electricity which has passed in a given time. Faraday has devised an instrument for this purpose, which he calls a *volta-electrometer*, it is shown in *Fig.* 48; *a* is a straight tube closed at the upper extremity and graduated; through the sides pass the platina wires *bb′*, being fused into the glass, and connected with two plates within; the tube is fitted by grinding into one mouth of a double-necked bottle, one half or two-thirds full of water, acidulated with sulphuric acid, to improve its conducting power. The tube is filled by inclining the bottle, and when an electric current is passed through it, the gases evolved, collect in the upper part of the tube, and displace the diluted acid, the stopper *c* being left open; when the graduated part of the tube *a* is filled with the mixed gases, the electric circuit may be broken by removing the wires connected with *bb′*, the stopper *c* replaced, and the metre tube refilled, by properly inclining the instrument; a second measure of gas is then collected, on re-establishing the circuit and so on.

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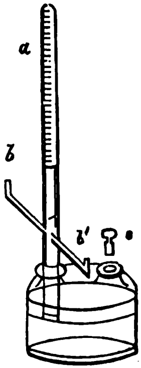
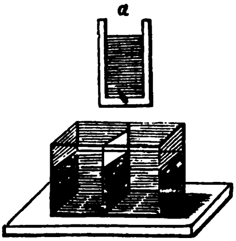
* An instrument to be described in another lecture.

Fig. 48.



In various experiments of decomposition, the little form of apparatus of which *Fig.* 49 is a sketch, and which I have copied from Brande's Manual of Chemistry, will be found exceedingly useful. It is a cell of plate glass, made by cementing five pieces together with transparent varnish and supporting them upon a wooden foot, in which they are fastened. The cell is about five or six inches long, and an inch broad, and may be divided into two parts by the insertion of the temporary diaphragm *a*, which is a small frame of cane with muslin stretched over it. When this is in its place, a separate electrode may be introduced on each side of

Fig. 49.



it, they may most conveniently consist of two pieces of thin platina foil, about four inches long and half an inch broad.

To show the evolution of chlorine at the anode or positive pole, fill the glass cell with weak salt and water, acidulated with muriatic acid, and coloured blue by a few drops of the sulphuric solution of indigo; then introduce the electrodes; in a few minutes the *anodic* division will be found to lose colour, and will finally become colourless, owing to the separation of chlorine, which by its bleaching powers destroys the blue of the indigo.

The presence of uncombined iodine may be demonstrated by filling the cell with a weak solution of *starch*, to which a little common salt and iodide of potassium have been added; then on passing the electric current through the liquid, the iodine will show itself at the anode by a beautiful blue colour, it being the property of this singular substance to strike a fine deep blue colour with starch.

The presence of *bromine* may be announced in a similar way by its *yellow colour*, and *fluorine* will be evinced by its action on glass.

Metals on the other hand, and all electro-positive bodies or cathïons, are developed at the cathode; this may be shown by a variety of beautiful experiments. Whenever solutions of metallic salts are electrized, their precipitations at the negative electrode are more or less perfectly observed: a plate of silver for instance, when immersed in a dilute solution of sulphate of copper, occasions no change; but if the silver be made the negative electrode, a precipitation of metallic copper instantly ensues. In the same manner solutions of lead, iron, &c., may be decomposed by metals which under common circumstances do not act on them. We saw at the last lecture that great inconvenience is occasioned by the precipitation of metallic zinc on the copper, the electro-positive metal in the compound voltaic battery.

Some of these results are due to *secondary* action, the meaning of which I will now endeavour to explain. Water and hydro-chloric acid are electrolytes, and are susceptible of decomposition by primary action. But nitric acid and ammonia are *not* electrolytes, although they are decomposed by the voltaic battery; how then is this to be accounted for? It will be understood, by considering the composition of these substances. Nitric acid is a compound of oxygen and nitrogen *intrinsically*, but it is also a compound, to the existence of which in the liquid state at any rate, *water* is essential. When therefore it is submitted to electrolytic action, the water of the solution is electrolyzed, and its hydrogen arriving at the negative electrode, decomposes the nitric acid, *water being reformed,* and nitrous acid produced: so also with a solution of ammonia, which consists of hydrogen and nitrogen in the proportions of three by volume of the former, and one of the latter, combined with water; when it is submitted to the action of electricity, the oxygen of decomposed water unites at the positive electrode with the hydrogen of the ammonia, and nitrogen gas is evolved. Numerous secondary actions are occasioned in this way, because the disunited elements are presented in a *nascent* form, which is peculiarly favourable to chemical action; and in many instances the electrode itself, which is commonly metallic, is chemically attacked by slow secondary actions of this nature, effected by very feeble currents. Becquerel was the first to procure several crystalline compounds, analogous to minerals, and the same has since been done in a more extended scale by Mr. Cross, whose experiments have recently excited so much attention; it thus appears that secondary results are *not confined* to cases where water is present.

Another instance of secondary electrolytic action is furnished by sulphuric acid, which is composed of one *atom* of sulphur and three of oxygen, when it is subjected to the action of the electric current, sulphur and hydrogen appear at the cathode, and hydrogen at the anode; but Faraday has shown that the sulphur is here the result of the *nascent* hydrogen upon the acid, and that in all cases of the true electrolytic decomposition of the sulphurets, the sulphur is evolved at the anode, and is hence to be placed among anïons.

In the voltaic current, when the metals are rendered electro-negative, they become attractive of all electro-positive bodies in general, and of each other, but repulsive of the opposite class, that is, of electro-negatives; this may be shown, by taking a plate of clean iron and immersing it in water, having first rendered it electro-negative; under these circumstances, it will remain for any length of time clean and bright as at first, whereas, under ordinary circumstances, it would become rusty; but if it is rendered electro-positive, it then corrodes much more rapidly than in plain water, that is, it is rendered *attractive* of oxygen, acids, and other solvent agents, of which in the opposite case it is repulsive.

From these facts, Davy was led to suppose that certain metallic substances, which under ordinary circumstances, are not acted on by water and acids, might be rendered active by communicating to them the positive electrical state; and on the contrary, that such metals as are easily attacked, might be preserved from chemical action, by rendering them negative. The following experiments will serve as illustrations:—

Silver is a metal that is not acted on by water, or by salt and water, or by muriatic acid; but if two strips of silver are made electrodes, and immersed in water, the anelectrode or positive pole will soon become discoloured, and a cloud will collect round it in the fluid, which is oxide of silver, but the cathelectrode will remain bright and clear as at first; here the silver has been rendered attractive of the oxygen of the water, with which it has entered into combination.

If for the water we substitute the solution of common salt or diluted hidrochloric acid, the negative silver will still remain bright, but the positive metal will attract chlorine, and become covered with a white incrustation of chloride of silver.

These effects are seen in a much more striking manner by substituting for the silver, metals that are, under common circumstances, energetically acted on by the fluids in which they are immersed; for instance, if two polished plates of iron are made electrodes, by connecting them with the extremes of the voltaic pile, and then plunged into diluted sulphuric or muriatic acid, liquids which rapidly corrode that metal, the cathelectrode will nevertheless remain bright, but the anelectrode will be rapidly oxidized and dissolved.

Again.—Fill the glass cell, *Fig.* 49, with a weak solution of salt in distilled water, to which a few drops of solution of prussiate of potash have been added, and immerse one of the iron plates in each partition, the negative side will still remain unchanged, but the positive side will soon, by its blue tinge, evince the active state of the iron, prussian blue being formed. If tincture of galls be substituted for the prussiate of potash, the solubility of the iron is shown by a black tinge.

But it does not require a galvanic pile to exhibit the prevention of chemical action by the agency of electricity. When a plate of zinc and another of copper are immersed in water, the copper becomes negative, and the zinc positive, as has been shown before; and although the chemical action on the positive metal is increased by combination, yet the action on the negative metal is proportionally diminished. For example, immerse a plate of sheet copper in a glass of diluted nitric acid, a slight blue colour which may be much increased by the addition of ammonia, will soon show that a portion of the metal has been dissolved, but if before its immersion it had been united to a plate of zinc, no blue colour will be perceptible, the zinc being alone dissolved. The use to which Davy attempted to apply this principle, was alluded to in the last lecture. One more example may be brought forward. Immerse a plate of polished iron into a glass of carbonated soda water, a portion will be dissolved in a few hours, as may be shown by tincture of galls. Now, tie a strip of zinc in close contact with the iron, and plunge both into the soda water, after the lapse of some days none of the iron will have been taken up; indeed it will remain as bright as when first put in; the reason is, that the iron by its combination with the zinc, has been *rendered* negatively electric, and consequently averse *to chemical* action.

From the preceding observations, it will be obvious, that electrolytic action tends to the separation both of proximate and ultimate elements. But in compounds of two elements, Faraday has shown that the ratio of combination, has an influence, which has hitherto been wholly overlooked. No two elements appear capable of forming more than one electrolyte. Hydrochloric acid, and fused metallic proto-chlorides, such as the chlorides of lead and silver, and proto-chloride of tin are readily decomposed, while bi-chloride of tin and other perchlorides, resist decomposition. In other words, those compounds with but very few exceptions, consisting of one atom or equivalent of an anïon, and one of a cathïon, are those only that are *directly* electrolytic, while other binary compounds of the same elements are not so; these differences may depend upon conducting power, for no substance that is not a conductor can be decomposed by galvanism, with the single apparent exception of periodide of mercury, which Faraday found to insulate while solid, but to conduct whilst liquid, and yet was not decomposed. Hence may be learnt why nitric and sulphuric acid and ammonia do not yield, *primarily*, to voltaic action, and hence also a powerful reason for classing water among binary compounds.

I have now drawn up, I hope, in a manner intelligible to the most unscientific person, and as far as my limits will allow, a brief outline of the present state of our knowledge of the chemical effects of galvanism. The subject, as you will easily perceive, is very far from being complete, indeed it appears, as with most scientific subjects, that the more there is discovered, the more remains behind, for each new discovery opens at the same time a fresh field for research; it is this which constitutes in fact, one of the greatest delights of physical investigations, for nothing would be more undesirable than to arrive at the real truths, to exhaust the subject and leave nothing for speculation; this however we need not fear, for the mine of nature is inexhaustible.

Before I quit this part of my subject, it may not be superfluous to give a summary of certain points developed by Dr. Faraday, and taken from his seventh series of Experimental Researches.—Philosophical Transactions, 1834, p. 111, but extracted immediately from Brande's Manual of Chemistry, fourth edition.

I. A single ïon, that is, one not in combination with another, will have no tendency to pass to either of the electrodes, and will be perfectly indifferent to the passing current, unless it be itself a compound of more elementary ïons, and itself subject to decomposition. Upon this fact is founded much of the proof adduced in favour of the new theory of electro-chemical decomposition put forward in a former series of these researches.

II. If one ïon be combined in right proportions with another strongly opposed to it in its ordinary chemical relations, that is, if an anïon be combined with a cathïon, then both will travel, the one to the anode, and the other to the cathode of the decomposing body.

III. If therefore an ïon pass towards one of the electrodes, another ïon must be also passing simultaneously to the other electrode, though from secondary action it may not make its appearance.

IV. A body decomposable directly by the electric current, that is, an electrolyte must consist of two ïons, and must give them up during the process of decomposition.

V. There is but one electrolyte composed of the same two elementary ïons, at least such appears to be the fact, dependant upon a law, *that only single electro-chemical equivalents of elementary ions can go to the electrodes, and not multiples.*

VI. A body not decomposable when alone, as boracic acid, is not directly decomposable by the electric current when in combination; it may act as an ïon, going wholly to the anode or cathode; but it does not give up its elements, except occasionally by chemical action.

VII. The nature of the substance of which the electrode is formed, provided it be a conductor, causes no difference in the electro-decomposition either in kind or degree; but it seriously influences by secondary action, the state in which the ions finally appear. Advantage may be taken of this principle, in combining and collecting such ions, as, if evolved in their free state, would be unmanageable.

VIII. A substance which, being used as the electrode, can combine altogether with the ion evolved against it, is also an ion, and combines in such cases in the quantity represented by its electro-chemical equivalent. All the experiments agree with this view, and it seems at present, to result as a necessary consequence. Whether in the secondary action that takes place where the ion acts, not upon the matter of the electrode, but upon that which is round it in the liquid, the same consequence follows, will require more extended investigation to determine.

IX. Compound ions are not necessarily composed of electro-chemical equivalents of simple ions. For instance—sulphuric, phosphoric, and boracic acids, are ions, but not electrolytes, that is, not composed of electro-chemical equivalents of simple ions.

X. Electro-chemical equivalents are always consistent, that is, the same number which represents the equivalent of a substance A, when separating from a substance B, will also represent A when separating from a third substance C. Thus eight is the electro-chemical equivalent of oxygen, whether separating from hydrogen, or tin, or lead; and one hundred and four is the electro-chemical equivalent of lead, whether separating from oxygen, chlorine, or iodine.

XI. Electro-chemical equivalents, coincide, or are the same with ordinary chemical equivalents.

Physiological effects of galvanism.—The action of galvanic electricity on a living animal, is the same as that of the common electric current, account being taken of the *intensity* of the one, and the *duration* of the other. When any part of the body is made to form part of the circuit of a voltaic pile, a distinct shock, resembling that of a large electrical battery weakly charged, is experienced every time the connection with the extremities is made, and besides this, if the pile be a large one, a continued aching pain is frequently felt, as long as the current is passing through the body, and if the slightest excoriation or cut happen to be in the path of the electrical current, the pain is very severe. The intensity of galvanic electricity is so low, that it requires good conductors for its transmission; unless therefore the skin is previously moistened, it will not force its way through the badly conducting cuticle, or outer skin. The most effectual mode of receiving the whole force of the battery, is to wet both hands with water, or with a solution of common salt, and to grasp a silver spoon in each, and then to make the connection between the poles of the battery. Another method is to plunge both hands into two separate vessels of water into which the extremities of the wires from the battery have been immersed. Volta has remarked, that the pain is of a sharper kind on those sensible parts of the body included in the circuit, which are on the negative side of the pile; and the same has been noticed with regard to the pungency of the common electrical spark.

It does not require a voltaic pile to exhibit the effects of galvanic electricity on the animal, whether living or dead. The simple application of a piece of zinc and one of silver to the tongue and lips, frequently gives rise, at the moment of the contact of the metals, to the perception of a luminous flash; but the most certain way of obtaining this result, is to press a piece of silver as high as possible between the upper lip and the gums, and to insert a silver probe into the nostrils, while at the same time a piece of zinc is laid upon the tongue, and then to bring the two metals into contact. Another mode is to introduce some tin foil within the eyelid, so as to cover part of the globe of the eye, and place a silver spoon in the mouth, which must then be made to communicate with the tin foil, by a wire of sufficient length; or, conversely, the foil may be placed on the tongue, and the rounded end of a silver probe applied to the inner corner of the eye, and the contact established as before. This phenomenon is evidently produced by an impression communicated to the retina optic nerve, and is analagous to the effect of a blow on the eye, which is well known to occasion the sensation of a bright luminous coruscation, totally independent of the actual presence of light. In the like manner the flash from galvanism is felt, whether the eyes are open are closed, or whether the experiment is made in day light or in the dark. If the pupil of the eye is watched by another person when this effect is produced, it will be seen to contract at the moment the metals are brought into contact; a flash is also perceived the moment the metals are separated from each other. When different metals are applied to different parts of the tongue, and made to touch each other, a peculiar taste is perceived; in order that this experiment should succeed, the tongue must be moist, the effect is materially diminished if it be previously wiped, and cannot be produced at all if the surface be quite dry. The quality of the metal laid upon the tongue influences the kind of taste which is communicated; the more oxidable metal giving rise to an acid, and the less oxidable metal to a distinct alkaline taste. Similar differences have been observed by Berzelius, with regard to the sensations excited in the tongue, by common electricity, directed in a stream upon that organ from a pointed conductor; the taste of positive electricity being acid, and that of negative electricity caustic and alkaline.

If the hind legs of a frog are placed upon a glass plate, and the crural nerve dissected out of one, made to communicate with the other, it will be found on making occasional contacts with the remaining crural nerve, that the limbs of the animal will be agitated at each contact. Aldini, the nephew of the original discoverer of galvanism, produced very powerful muscular contraction, by bringing a part of a warm blooded and of a cold blooded animal into contact with each other, as the nerve and muscle of a frog, with the bloody flesh of the neck of a newly decapitated ox, and also by bringing the nerve of one animal into contact with the muscle of another.

If a crown piece be laid upon a piece of zinc of larger size, and a living leech placed upon the silver coin, it suffers no inconvenience as long as it remains in contact with the silver only, but the moment it has stretched itself out and touched the zinc, it suddenly recoils, as if from a violent shock. An earth worm exhibits the same kind of sensitiveness. The convulsive movements excited in the muscles of animals after death, by a powerful galvanic battery, are extremely striking, if the power is applied before the muscles have lost their contractibility. Thus if two wires connected with the poles of a battery of a hundred pair of plates, are inserted into the ears of an ox or sheep, when the head is removed from the body of the animal recently killed, very strong actions will be excited in the muscles of the face every time the circuit is completed. The convulsions are so general, as often to induce a belief that the animal has been restored to life, and that he is enduring the most cruel sufferings. The eyes are seen to open and shut spontaneously; they roll in the sockets as if again endued with vision; the pupils are at the same time widely dilated; the nostrils vibrate as in the act of smelling; and the movements of mastication are imitated by the jaws. The struggles of the limbs of a horse galvanised, soon after it has been killed, are so powerful, as to require the strength of several persons to restrain them. I shall here detail the experiments of Dr. Ure on the body of the murderer Clydesdale, performed on the 4th of November, 1818, and published in the Journal of Science and Arts of the following January. They will serve to convey a pretty accurate idea of the wonderful physiological effects of this agent, and will be impressive from their conveying the most terrific expressions of human passion, and human agony.

"The subject of these experiments, was a middle sized, athletic, and extremely muscular man, about thirty years of age. He was suspended from the gallows nearly an hour, and made no convulsive struggle after he dropped. While a thief who was executed along with him, was violently agitated for a long time. He was brought into the anatomical theatre of our university, about ten minutes after he was cut down. His face had a perfectly natural aspect, being neither livid, nor tumefied, and there was no dislocation of the neck.

"Dr. Jeffray, the distinguished professor of anatomy, having on the preceding day, requested me to perform the galvanic experiments, I sent to his theatre the next morning with this view, my minor voltaic battery, consisting of two hundred and seventy pairs of four inch plates, with wires of communication, and pointed metallic rods with insulating handles, for the more commodious application of the electric power. About five minutes before the police officers arrived with the body, the battery was charged with dilute nitro-sulphuric acid, which speedily brought it into a state of intense action. The dissections were skilfully executed by Mr. Marshall, under the superintendence of the Professor.

Experiment 1.—A large incision was made in the nape of the neck just below the occiput; the posterior half of the atlas vertebra was then removed by bone forceps; when the spinal marrow was brought into view, a profuse flow of fluid blood gushed from the wound, inundating the floor. A considerable incision was at the same time made in the left hip, through the great gluteal muscle, so as to bring the sciatic nerve into sight, and a small cut was made in the heel, from neither of these did any blood flow. The pointed rod connected with one end of the battery, was now placed in contact with the spinal marrow, while the other rod was applied to the sciatic nerve; every muscle of the body was immediately agitated with convulsive movements, resembling a violent shuddering from cold. The left side was most powerfully convulsed. On moving the second rod from the hip to the heel, the knee being previously bent, the leg was thrown out with such violence as nearly to overturn one of the assistants, who in vain attempted to prevent its extension.

" Experiment 2.—The left phrenic nerve was now laid bare at the outer edge of the *sternothyroideus* muscle, from three to four inches above the clavicle; the cutaneous incision having been made by the side of the sterno-cleido-mastoideus. Since this nerve is distributed to the diaphragm, and since it communicates with the heart through the eighth pair, it was expected by transmitting the galvanic current along it, that the respiratory process would be renewed. Accordingly a small incision having been made under the cartilage of the seventh rib, the point of the one insulating rod was brought into contact with the great head of the diaphragm, while the other point was applied to the phrenic nerve in the neck. This muscle the main agent of respiration was immediately contracted, but with less force than was expected. Satisfied from ample experience on the living body, that more powerful effects can be produced by galvanic excitation, by leaving the extreme communicating rod in close contact with the parts to be operated on, while the electric chain or circuit is completed by running the end of the wires along the top of the plates in the last trough of either pole, the other wire being steadily immersed in the last cell of the opposite pole, I had immediate recourse to this method. The success of it was truly wonderful, full, nay, laborious breathing instantly commenced, the chest heaved and fell, the belly protruded, and again collapsed with the relaxing and retiring diaphragm. This process was continued without interruption, as long as I continued the electric discharges. In the judgment of many scientific friends who witnessed the scene, this respiratory experiment was perhaps the most striking ever made with philosophical apparatus.

" Let it also be remembered, that for full half an hour before this period, the body had been well nigh drained of its blood, and the spinal marrow severely lacerated. No pulsation could be perceived meanwhile at the heart or wrist; but it may be supposed that but for the evacuation of blood, the essential stimulus of that organ, this phenomenon might also have occurred.

" Experiment 3.—The super-orbital nerve was laid bare in the forehead, as it issues through the supra-ciliary foramen in the eyebrow; the one conducting rod being applied to it, and the other to the heels, most extraordinary grimaces were exhibited every time the electric discharges were made, by running the wire in my hand over the edges of the plates in the last trough, from the two hundred and twentieth to the two hundred and seventieth pair, thus fifty shocks, each greater than the preceding ones, were given in two seconds. Every muscle of his countenance was simultaneously thrown into fearful action, rage, horror, despair, and anguish, and ghastly smiles united their hideous expression in the murderer's face, surpassing far the wildest representations of a Fuseli, or a Kean. At this period several of the spectators were obliged to leave the room from terror or sickness, and one gentleman fainted.

"Experiment 4.—The last galvanic experiment consisted in transmitting the electric power from the spinal marrow to the ulnar nerve, as it passes by the internal condyle at the elbow; the fingers now moved nimbly, like those of a violin performer; an assistant who tried to close the fist, found the hand to open forcibly in spite of his efforts. When one rod was applied to a slight incision on the top of the forefinger, the fist being previously clenched, the fingers extended instantly, and from the convulsive agitation of the arm, he seemed to point to the different spectators, some of whom thought he had come to life. About an hour was spent in these operations."

In these experiments the positive wire was always applied to the *nerve*, and the negative to the *muscles*, that this is important, will appear from the following facts:

Let the posterior nerve of a frog be prepared for electrization, and let it remain till its voltaic susceptibility is considerably blunted, the crural nerves being connected with a detached portion of the spine; plunge the limbs into one wine glass full of water, and the crural nerves &c. into another glass; then take a rod of zinc in one hand, and a silver tea spoon in the other, plunge the former into the water of the limbs' glass, and the latter into the water of the nerves glass, without touching the frog itself, and gently strike the dry parts of the metals together; feeble convulsive movements or mere twitching of the fibres, will be perceived at each contact; reverse now the position of the metal rods, and on renewing the contact between them, very lively convulsions will take place, and if the limbs are skilfully disposed in a narrow conical glass, they will probably spring out to some distance. Or, let an assistant seize in his moistened left hand the spine and nervous cords of the prepared frog, and in his right a silver rod, and let another person lay hold of one of the limbs with his right hand, and a zinc rod in the moist fingers of the left; on making the contact, feeble convulsive twitching will be perceived as before; now let the metals be reversed; on renewing the contact, lively movements will take place, which become very conspicuous; if one limb be held nearly horizontal, while the other hangs freely down, at each touch of the voltaic pair, the drooping limb will start up and strike the hand of the experimenter.

Hence for the purposes of resuscitating the dormant irritability of the nerves, as Dr. Ure remarks, or the contractility of their subordinate muscles, the positive pole must be applied to the former, and the negative to the latter.

But the most interesting researches, on the relation *between voltaic* electricity, and the phenomena of life, are those of Dr. Wilson Philip, which are published in the Philosophical Transactions.

In his earlier researches, he endeavoured to prove that the circulation of the blood, and the action of the involuntary muscles, are independent of the nervous influence. In a paper, read in January, 1816, he showed the immediate dependance of the secretory function on the nervous influence. The eighth pair of nerves distributed to the stomach, and subservient to digestion, were divided by incisions in the necks of several rabbits; after the operation, the parsley which they ate remained without alteration in their stomachs, and the animals, after evincing much difficulty in breathing, appeared to die of suffocation. But when in other rabbits similarly treated, the galvanic power was distributed along the nerve below its section, to a disc of silver placed closely in contact with the skin of the animal opposite to its stomach, no difficulty of breathing occurred. The voltaic action being kept up for twenty-six hours, the rabbits were then killed, and the parsley was found in as perfectly digested a state as that in healthy rabbits fed at the same time; and their stomachs evolved the smell peculiar to that of rabbits during digestion. These experiments were several times repeated with similar results.

Thus a remarkable analogy is shown to exist between the galvanic energy and the nervous influence, the former of which, may be made to supply the place of the latter, so that while under it, the stomach, otherwise inactive, digests food as usual.

Dr. Philip was next led to try galvanism as a remedy in asthma. By transmitting its influence from the nape of the neck to the pit of the stomach, he gave decided relief in every one of twenty-two cases, of which four were in private practice, and eighteen in the Worcester infirmary. The power employed varied from ten to twenty-five pairs.

These results of Dr. Philip have since been confirmed by Dr. Clarke Abel, of Brighton, (Journ. Sc. ix.) this gentleman employed in one of the repetitions of the experiments, a comparatively small and in the other a considerable power. In the former, although the galvanism was not of sufficient power to occasion evident digestion of the food, yet the efforts to vomit and the difficulty of breathing, constant effects of dividing the eighth pair of nerves, were prevented by it. The symptoms recurred when it was discontinued, but vanished on its re-application. "The respiration of the animal," he observes, "continued quite free during the experiment, except when the disengagement of the nerves from the tin foil, rendered a short suspension of the galvanism necessary, during their re-adjustment. The non-galvanized rabbit wheezed audibly, and made frequent attempts to vomit. In the latter experiment, in which greater power of galvanism was employed, digestion went on as in Dr. Phillips's experiments.

It had been suggested by an eminent French physiologist, M. Gallois, that the motion of the heart depends entirely upon the spinal marrow, and immediately ceases when the spinal marrow is removed or destroyed. But Dr. Philips rendered rabbits insensible by a blow on the occiput, the spinal marrow and brain were then removed, and the respiration kept up by artificial means; the motion of the heart and circulation were carried on as usual. When spirit of wine or opium was applied to the spinal marrow or brain, the rate of circulation was accelerated. These experiments appear to confute the notion of M. Gallois.

The general inferences deduced by Dr. Philip from his numerous experiments are, that voltaic electricity is capable of effecting the formation of the secreted fluids when applied to the blood, in the same way in which the nervous influence is applied to it, and that it is capable of occasioning an evolution of caloric from arterial blood. When the lungs are deprived of the nervous influence, by which their function is impeded, and even destroyed; when digestion is interrupted by withdrawing this influence from the stomach, these two vital functions are renewed by exposing them to the influence of a galvanic trough. "Hence," says he, "galvanism seems capable of performing all the functions of the nervous influence in the animal economy; but obviously, *it cannot excite the functions of animal life, unless when acting on parts endowed with the living principle.*"

My limits will not allow me to extend my remarks on this most interesting department of my subject, I must therefore refer you to a recent work on electricity by Mr. Leithead, secretary to the London Electrical Society, in which the electro-physiological theory is discussed with considerable ability, and which you will find in other respects well worth perusal. I shall only further observe on this head, that it seems probable when apparent death supervenes from suffocation with noxious gases, and in cases of death-like lethargy or suspended animation, &c., and when there is no organic lesion, that a judiciously directed galvanic experiment, will, if any thing will, restore the activity of the vital functions. On the principle developed by Dr. Philip, we should transmit along the channel of the nerves, that substitute for nervous influence, or that power which may perchance awaken its dormant faculties. "Then indeed," as Dr. Ure well observes, "fair hopes may be entertained of deriving extensive benefit from galvanism, and of raising this wonderful agent to its rank among the ministers of life and health to man."

There are some remarkable instances of the generation of electricity in living animals, to whom the power seems principally to be given as a means of defence. Of these animals the Raia Torpedo appears to have been noticed at a very early period, since we find a description of its properties in the writings of Pliny, Appian, and others. It inhabits the Mediterranean and North Seas; its weight when full grown is about eighteen or twenty pounds. When touched it communicates a benumbing sensation, and by repeated contacts gives a series of electric shocks. In the Philosophical Transactions 1773 and 1775, there are accounts of some experiments of Mr. Walsh on this animal. He placed a living torpedo on a wet napkin, and formed a communication through five persons, all of whom were insulated. The person at one extremity touched some water, in which a wire, proceeding from the wet napkin, terminated; the last person in the series having a similar mode of communication with a wire, which at intervals could be brought into contact with the back of the animal. In this manner shocks were communicated to the five, and afterwards to eight persons. Mr. Walsh could not succeed in affecting the electroscope, or in obtaining a spark by this electricity. But he observed that every time the animal gave a shock, which was not generally perceptible beyond the finger with which it was touched, a contortion of the body followed, as if the animal were anxious to make its escape; its eyes were also depressed, so that he could tell by observing the eyes, when the animal attempted to make a discharge, even upon non-conducting bodies. Mr. Cavendish constructed an artificial torpedo of wood, connected with glass tubes and wires, and covered with a piece of sheep-skin leather. To render the effect of this instrument more like that of the animal, with regard to the difference of the shock in and out of water, it was necessary to substitute thick leather in the place of the wood, and with this improvement, the apparatus succeeded admirably. In air the sensation of the shock was experienced at the elbows, but under water it was confined chiefly to the hands. On touching this artificial torpedo under water, a shock was obtained as powerful as if it had been touched by both hands. Being touched under water with two metallic spoons it gave no shock, but in air, the shock was very strong. Cavendish also made an estimate between the strength of his artificial torpedo, and that dissected by Hunter, with reference to surface. His own battery consisted of seventy-six feet of coated surface, and he calculated that the animal retained a charge fourteen times as great as that of the battery, or was equivalent to one thousand and sixty-four feet of coated glass.

In the Philosophical Transactions for 1773, there is a detail of the anatomical structure of this curious fish from the pen of the celebrated Hunter.

"The nerves," he says, "inserted into each electric organ, arise by three large trunks from the latter and posterior parts of the brain. The first of these in its passage outwards turns round a cartilage of the cranium, and sends a few branches to the first gill, and to the anterior part of the head, and then passes into the organ at its anterior extremity. The second trunk enters the gills between the first and second openings, and furnishes it with small branches, passing into the organ near the middle. The third trunk after leaving the skull, divides into two branches, which pass to the electric organ through the gills, one between the second and third openings, the other between the third and fourth, giving small branches to the gill itself. These nerves having entered the organs, ramify in every direction between the columns, and send in small branches on each partition where they are lost.

"The magnitude and number of the nerves bestowed on these organs, in proportion to their size, must on reflection, appear as extraordinary as the phenomena they afford. Nerves are given to parts either for sensation or for action. Now if we except the more important senses of seeing, hearing, smelling, and tasting, which do not belong to the electric organs, there is no part, even of the most perfect animal, which in proportion to its size, is so liberally supplied with nerves, nor do the nerves seem necessary for any sensation which can be supposed to belong to the electric organs. And with respect to action, there is no part of any animal with which I am acquainted, however strong and constant its natural actions may be, which has so great a proportion of nerves. If it be then probable that these nerves are not necessary for the purposes of sensation or action, may we not conclude that they are subservient to the formation, collection, or management of the electric fluid, especially as it appears evident from Mr. Walsh's experiments, that the will of the animal does absolutely controul the electric powers of the body which must depend upon the energy of the nerves."

At the request of his illustrious brother, Dr. John Davy undertook a series of experiments at Malta, on this form of electricity. He succeeded in communicating distinct magnetism to a needle by the electricity of a small torpedo, and in throwing into violent motion the needle of a magnetic multiplier; but he failed in obtaining a spark, or any igniting power, nor could he affect the electroscope, or obtain any indications of attraction and repulsion in air.

His electro-chemical results were highly satisfactory; he decomposed strong solutions of common salt, nitrate of silver, and superacetate of lead; and he inferred that the *under* surface of the organ corresponds to the zinc, and the upper surface to the copper extremity of the voltaic battery.

The gymnotus is another fish possessed of electrical properties; it is a native of the warmer regions of America, and Africa, inhabiting large rivers, especially those of Surinam. In Africa it chiefly occurs in the branches of the Senegal. These animals were first described by Richer, in 1677, and their anatomical structure by Mr. Hunter, in the 63rd and 65th volumes of the Philosophical Transactions. Their electric organs consist of alternations of different substances and are most abundantly supplied by nerves; their too frequent use is succeeded by debility and death. That these organs are not essential to the animals, is proved by their thriving after they have been removed.

By touching this fish with one hand a shock is felt in the fingers, wrist, and elbow. The hand of one person being held in water at the distance of three feet from the animal, upon a second person's irritating the eel, the former will receive a shock. Dr. Williamson placed a cat-fish in the same vessel of water with the eel, and then dipped his own hand in the water. The gymnotus swam up to the fish, but turned away without offering any violence to it, it soon returned, and after regarding attentively the cat-fish for some seconds, gave it a shock, which made it turn up its belly, and continue motionless. The shock was perceptible to Dr. Williamson at the same time. Whenever fish that had been thus rendered motionless were removed to another vessel they recovered.

In his Tableau Physique des Régiones Equitoriales, &c., Humboldt has given some curious details respecting the electrical eel, which inhabits the rivers and lakes of the low provinces of Venezuela and the Caracas. It is met with most frequently in the stagnant pools, dispersed at intervals over the plains which extend from Oronoco to the Apuré. The old road near Urutica has even been abandoned on account of the danger experienced in crossing a ford, where the mules were from the effects of the shocks often paralyzed and drowned. Even the angler sometimes receives a stroke conveyed along his rod and line. These eels are about six feet in length, and occasion a highly painful sensation, more resembling the effect of a blow on the head, than the shock of a common electric discharge; a peculiarity of effect referable perhaps to a great quantity of electricity of small intensity. The following *particulars* given by Humboldt, and taken from the

Edinburgh Review, vol. xvi., p. 250, are worth inserting.

"The Indians entertain such a dread of the gymnotus, and show so much reluctance to approach it when alive and active, that Humboldt found extreme difficulty in procuring a few to serve as the subjects of experiment. For this express purpose, he stopped some days on his journey across the Llanos to the river Apurè, at the small town of Calaboze, in the neighbourhood of which he was informed they were very numerous. But though his landlord took the utmost pains to gratify his wish, he was constantly unsuccessful. At last, he determined to proceed himself to the spot, and was conducted to a piece of shallow water, stagnant and muddy, but of the temperature of 79°, surrounded by a rich vegetation of the great Indian fig trees, and the odoriferous sensitive plants. Here he soon witnessed a spectacle of the most novel and extraordinary kind. About thirty horses and mules were quickly collected from the adjacent savannahs, where they run half wild; these the Indians drove into the marsh. The gymnoti roused from their slumbers by the noise and tumult, mount near the surface, and swimming like so many livid water-serpents, briskly pursue the intruders, and gliding under their bellies, discharge through them the most violent and repeated shocks. The horses convulsed and terrified, their mane erect, and their eyes staring with pain and anguish, make unavailing struggles to escape. In less than five minutes two of them sunk under the water and were drowned. Victory seemed to declare for the eels; but their activity now began to relax; fatigued by such expence of nervous energy, they shot their electric discharges with less frequency and effect. The surviving horses gradually recovered from the shock, and became more composed and vigorous. In a quarter of an hour the gymnoti finally retired from the contest, and in such a state of langour and complete exhaustion, that they were easily drawn on shore by help of small harpoons fixed on cords."

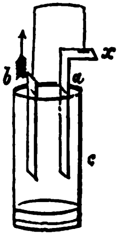
I regret that my limits will not allow of my pursuing further this interesting part of the subject of galvanism. But as I have, before I conclude this lecture, to make some remarks on the theory of the voltaic pile, I must beg to refer you again to Mr. Leithead's work, in which the physiological effects of electricity is entered into, considerably in detail.

The electricity of the pile was attributed by its discoverer Volta, to the contact of the different metals, and he regarded the interposed solutions as imperfect conductors, admitting the transfer of electricity, when the circuit was completed; and when incomplete, throwing the whole by induction into an electro-polar state. Davy considered the electric state of the pile to be due partly to the contact of the opposed metals, and partly to the chemical action exerted on them by the liquid. He concluded, to use his own words, Philosophical Transactions, 1826, p. 389, " that chemical and electrical attractions are produced by the same cause, acting in one case on *particles*, in the other on masses of matter: and that the same property under different modifications, is the cause of all the phenomena exhibited by different voltaic combinations." Dr. Wollaston on the other hand, referred the phenomena, solely to chemical action. He even attributed the *electricity* of the common machine to the oxidizement of the amalgam, and found, contrary to the experiments of his great contemporary, that the electrical machine was not active in atmospheres of hydrogen, nitrogen, or carbonic acid.

That this last theory is the true one, we have, I imagine, ample proof from the recent researches of Dr. Faraday; he has produced electricity in a voltaic arrangement, *quite independent of contact.*

A plate of zinc, (*Fig.* 50,) was cleaned and bent in the middle to a right angle; a piece of platinum about three inches long, and half an inch wide, *b*, was fastened to a platinum wire, and the latter bent as in the figure. These two pieces of metal were arranged as shown in the sketch; at *x* a piece of folded bibulous paper moistened in a solution of iodide of potassium was placed on the zinc, and was pressed upon by the end of the platinum wire; when under these circumstances, the plates were dipped in the diluted nitric and sulphuric acids contained in the vessel *c*, there was an immediate effect at *x*, the iodide being decomposed, and iodine appearing at the anode, that is, against the end of the platinum wire. As long as the lower ends of the plates remained in the acid, the electric current proceeded, and the decomposition proceeded at *x*. On removing the end of the wire from place to place on the paper, the effect was evidently very powerful, and on placing a piece of turmeric paper between the white paper and the zinc, both papers being moistened with a solution of iodide of potassium, alkali was evolved at the *cathode* against the zinc, in proportion to the evolution of iodine at the

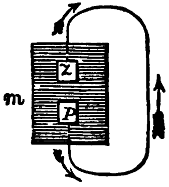
Fig. 50.



anode; the galvanometer also showed the passage of an electrical current; and we have thus a simple circle of the same construction and action, as those described in the last lecture, except in the absence of metallic contact.

The same profound philosopher has given the following illustrations. Let Z and P in *Fig.* 51, represent a piece of pure zinc and platina immersed in a vessel of diluted sulphuric acid, and connected by a long wire of either metal, chemical action immediately commences on the zinc, it becomes oxidized, and a current of electricity passes through the connecting wire in the direction indicated by the small arrows. The *direction* of this current never changes, and it may be compared with the electricity of the common machine, for if the prime conductor and the rubber are connected by a wire, the electricity is said to be passing from the conductor through the wire to the rubber. (See Lectures one and two.) So, in the above experiment, the electric current is from P through the wire to Z. If the connection between the metals is broken, the current ceases, and the action on the zinc is stopped. Hence the question—Is the real cause of the current the chemical action on the oxidable metal, or is it due to contact? This question is now fully cleared up.

Fig. 51.



2. Let *n* and *o*, (*Fig* 52,) be two vessels similar to the last, and each containing plates of platina and zinc, and let each pair of zinc, and each pair of platina

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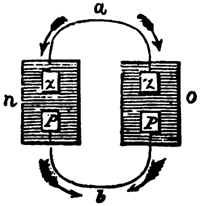
The arrow in *Fig.* 51 should have been made to point in the same direction; the current passing from P to Z. From an oversight, one of the arrows in the above figure is reversed.

be connected by distinct wires, *a* and *b*; under these circumstances, there will be neither chemical or electrical action. But if a wire be stretched from *a* to *b*, a current of electricity will run up it, dividing right and left as represented by the arrows in the figure; both zincs will undergo oxidation, and both platinas evolve hydrogen gas. Now let the diluted acid in *o* be replaced by a solution of iodide of potassium, still the current will exist as before, and in the vessel *o*, iodine will combine with the zinc, and hydrogen appear on the platina. Now let the cross wire be removed, thus destroying the condition of metallic contact, and chemical action; the current from *b* across to *a*, of course no longer exists, that from *a* through the vessel *n* to *b* will be weakened, and the chemical action in *n* much diminished; but the current through *a*, from *o* to *b*, will be actually inverted, and the chemical action in *o* will be inverted also, and iodine will now appear in its free state, against the platinum *p*, instead of combining with the zinc, and the hydrogen will appear on the opposite side.

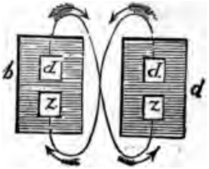
Fig. 52.



"Hence it is not only proved, that metallic contact is not essential, and that chemical action is the cause of the phenomena, but also, that two distinct chemical actions may be opposed, and the weaker made to yield to the stronger; and thus *electro-chemical excitation, and electro-chemical decomposition, are shown existing together, in the simplest manner, as cause and effect.*"

Again, in *Fig.* 53, let the connecting wires be divided, and each be connected with the dissimilar metal in the other vessel, and it will be found that the forces in *p* and *q* aid and exalt each other, instead of exerting a mutual opposing action; a simple inspection of the arrangement will show that this must be the case, that it is the *principle of the voltaic pile or trough*, and that it will be the same in three hundred or three thousand such actions.

Fig. 53.



Professor Daniel has also done much to elucidate the theory of the voltaic battery. He employs an apparatus in which it is easy to illustrate, in a striking manner, the difference of effect with regard to the quantity and intensity of the electric current; he designates it by the name of the *dissected battery*. It consists of ten cylindrical glass cells, capable of holding the fluid electrolytes, in each of which two plates of metal are immersed, each plate communicating below by means of a separate wire, which is made to perforate a glass stopper closing the bottom of the cell, with a small quantity of mercury contained in a separate cup, underneath the stopper, and with which, electric communication may be made at pleasure, through other wires passing out of the cups on each side. The active elements of the circuit, which he adopts as standards of comparison are, for the metal plates of platina and amalgamated zinc, three inches in length by one in breadth; and for the electrolyte, water acidulated with sulphuric acid. Above each platinum plate is suspended a graduated glass jar, filled with the same liquid, and serving the purpose of a voltameter, to indicate the amount of action in each cell. By *means of this* dissected battery, the quantity of the electric current, is exhibited by uniting the plates of the respective metals, so as to constitute a single pair; and the intensity, when the separate pairs are combined in alternate series. The influence of different modifications of these arrangements—the effects of the interposition of the pairs in the reverse order—of the substitution of different metals for some of the regular series—of changes in the constitution of the electrolyte, and of other changes, operating both as causes of retardation and assistance to the current, may readily be seen and measured.

Professor De la Rive, of Geneva, has examined the theories of voltaic electricity with much attention. In the year 1828 he published a memoir, entitled "Analysis of the circumstances which determine the direction and intensity of the electric current in a voltaic pair." An abstract of this memoir has lately appeared in the London and Edinburgh Philosophical Magazine, (Vol. xi. No. 67.) But I regret that my limits will only allow of a short notice of it.

1st.—He strongly contends that insuring the absence of calorific and mechanical action, no electricity can be developed in bodies, when they do not undergo chemical action. All the experiments that have hitherto been brought forward in opposition to this, are unsatisfactory, owing to the very great difficulty of securing the absence of chemical action in their prosecution. Messrs. Pfaff and Becquerel employed a condenser, of which one of the plates was copper, and the other zinc, between which, a communication was established by means of an insulated arc of copper; the plates were put in vacuo, in hydrogen, or in azote carefully dried, or the copper plate was gilt, and the zinc plate covered with a thin coating of lac varnish. But De la Rive says, it can easily be shown, that in one case sufficient air (atmospheric) is always present to produce slight oxidation of the zinc; and in the other, the coating of varnish is too thin to prevent oxidation, which took place through the pores the alcohol produced by evaporation.

But chemical action may be entirely excluded. Pairs of platina and rhodium, and pairs of platina and gold, give no current in very pure nitric acid, nor do pairs of platina and palladium in dilute sulphuric acid, but a drop of hydrochloric acid in the one, or nitric acid in the other, immediately determines one. The following experiment was made:

Two plates of perfectly polished steel were immersed in a flask containing solution of potash; one was insulated, and the other metallically fixed by its extremity to a plate of platina immersed in the same liquid; the two steel plates were fixed in a cork, the upper end of each passing into the air. In three years the immersed surfaces had not lost any degree of polish, yet, according to Volta, the plate connected with the platina ought to have been oxidated; particularly since potash is a good conductor of electricity: the ends outside the cork were both oxidated, the associated plate by far the most so; hence it follows, that oxidation must have commenced in order to the existence of an electric current; the current produced by this oxidation decomposes water, and in consequence, determines a stronger oxidation on the steel plate connected with the platina, and this oxidation in its turn increases the energy of the current, and is thus both cause and *effect.*

He says sufficient attention has not been paid to the formation of coatings of *suboxide* on the surfaces of metals, which sometimes take place with great rapidity, and may be seen, by comparing the recently brightened surface of a metal, with one that has for some time been exposed to the air. If a bright surface be rubbed with a cork, the metal is always negative; but if the rubbing be deferred for a time, the metal is always positive, even in dry air; this is evidently occasioned by the formation of a coating of suboxide, which is removed by the rubbing substances, the friction afterwards taking place between the metal and its oxide, which causes the former to be positive. Again, if a metal which has been brightened and allowed to remain for some time in dry air, be fixed to the negative pole of a battery, and a plate of platina to the positive, and both immersed in dilute sulphuric acid, oxygen appears at the positive pole some seconds before the hydrogen shows itself at the negative, which shows that the latter must have been employed in deoxidizing the negative metal.

The experiment of Becquerel of immersing pure oxyd of manganese and platina in pure water, is also unsatisfactory, for the current is not perceptible for more than half an hour, during which time the electricity due to chemical action, (either from the slight deoxidation of the peroxide, or the formation of a hydrate) is accumulating—here the platina is positive.

"All chemical action disengages electricity; but the electricity disengaged is not, in every case, nor under every form, proportional to the vivacity of the chemical action. Two principal circumstances may explain this anomoly: viz., the immediate recomposition in a larger or smaller proportion of the two electricities, at the points at which they are separated by chemical action; and the particular nature of this action, which according to the bodies between which it is exerted gives rise to electric effects more or less intense."

It is necessary here carefully to distinguish the electricity *perceived* from the electricity *produced:* the latter must evidently be proportional to the extent of the chemical action; that is, that in a given time it depends upon the number of *chemical atoms* which are combined, and consequently upon all the other circumstances which may have exerted an influence upon the number of these combinations, (the extent of the surface exposed to chemical action, the vivacity of that action, &c.)—The electricity perceived is a portion of the electricity produced, a portion which depends on the relative conductability of the bodies entering into the system in which the electricity is propagated, upon the disposition of the different parts of the system, and upon the nature of the apparatus to be employed in showing the presence of the electricity, &c., circumstances which all have an influence on the degree of facility with which the two electric principles follow some certain course, or become again immediately united to the same surface from which by chemical action they are separated.

When a capsule of platina filled with sulphuric or diluted nitric acid, is placed upon the plate of a condenser, and a plate of zinc held in the fingers is immersed in it, a very feeble charge is given to the plate of the condenser, although the chemical action *may have* been very lively: the reason is, not that there has not been an enormous disengagement of electricity, a fact which may be proved by employing this electricity in producing a current; but in this experiment the negative electricity developed in the zinc unites with the positive with much greater facility than it can pass through the fingers and the body of the experimenter, in order to lose itself in the earth. There will therefore be only a very feeble positive tension, often scarcely any; but if the diluted acid is replaced by concentrated sulphuric acid, though the chemical action will be less lively, the electric tension will be much stronger, this acid being a very bad conductor, and the passage of the electricity from the liquid to the metal immersed in it, being extremely difficult, the two electricities uniting, on the surface attacked, in much smaller proportions: if, instead of a piece of metal, a piece of wood rather moist is immersed in the concentrated sulphuric acid, the *positive tension* acquired by the acid is still stronger. If a capsule made of an oxidable metal be employed, and after heating it, a few drops of a liquid capable of attacking it at that high temperature in ever so small a degree (pure water is sufficient) be poured into it, a quantity of negative electricity is developed, which is sufficiently strong to be sensible without the assistance of the condenser, and even to give sparks. In this case the drop of liquid injected into the heated capsule, is converted into vapour while it is attacking the metal, and carries off with it the positive electricity which cannot then combine immediately with the negative electricity left in the metal: but if even the smallest quantity of liquid remains in the capsule, unvaporized, the immediate recomposition takes place, and only very feeble traces of negative electricity can be obtained. If the electricity developed by the action of a gas, or by that exerted by a humid body, such as the hand, or a piece of wood, upon the metal with which it is in contact, be often much stronger than the electricity resulting from the much livelier action of a liquid, the reason is, that in the former case, the *immediate recomposition* of the two electric principles, is almost *null*, in consequence of the imperfect conductibility of the exciting bodies, and that the electricity produced is almost entirely perceived. There *is*, however, a slight recomposition, for the negative tension of an insulated metal is sensibly augmented by giving a *translatory* motion to the gas which attacks its surface; the consequence of which is, that the positive electricity accumulated in the gas, being removed with it, cannot unite with the negative left in the metal. The principle of the immediate recomposition of the two electricities, applies also to the production of electric currents in a pair. In very lively chemical actions the larger proportion of the electricities developed, often undergoes this recomposition; a small part only runs through the whole circuit, especially if it be not a very good conductor; which is the reason that the strongest currents are not always those produced by the most lively chemical actions, and that in a pair the metal most attacked *is not always the positive one*; that is, the one whence the current commences. However, the latter case occurs only when each of the two metals of the pair are immersed in different liquids. A single example may be adduced:—a plate of zinc is immersed in concentrated sulphuric acid, and a plate of copper in nitric acid; the two acids are immediately in contact, and the two metallic plates communicate by means of the wire of a galvanometer. In this pair the zinc is positive, though it is much less attacked than the copper, because the two electricities developed by the action of the sulphuric acid on the zinc, can be more easily reunited by making the tour of the circuit, than by passing from the sulphuric acid to the zinc, and reciprocally; while on the contrary the two electricities developed by the action of the nitric acid on the copper, reunite immediately with the greatest facility, in consequence of the conductibility of the nitric acid, and the ready passage of the electricity from that acid to the copper; while to make the circuit, they would be obliged to traverse the concentrated sulphuric acid which is a very imperfect conductor, and pass from the zinc to the acid,—a very difficult passage. Two circumstances prove the exactitude of this explanation: 1.—The same result is obtained in the preceding experiment, by substituting a plate of zinc similar to that which is immersed in the sulphuric acid, for the plate of copper immersed in the nitric acid. 2.—If a capsule of platina be put upon the plate of a condenser, and filled in succession with nitric acid, and concentrated sulphuric acid, and a plate of copper or zinc held between the fingers, be immersed in the former liquid, and a plate of zinc in the latter, a much stronger positive electricity is obtained in the second case than in the first.

In applying these principles to the explanation of the theory of the voltaic pile, De la Rive remarks, that the use of the pile is to facilitate the passage of the current through imperfect conductors, and not to *increase the quantity of electricity;* for the utmost that can be affected by a pile composed of a certain number of similar pairs, is to compel all the electricity produced by only *one* of its pairs, to pass through the conducting body, which connects its poles. The only means of attaining this object, is to separate the two metals of a pair, by other pairs, as similar to the first as possible. These intermediate pairs, the number of which should correspond to the more or less imperfect conductibility of the bodies interposed, will each produce as much electricity, as the extreme pairs. But these electricities do *not pass through the conductor*, they only compel the electricities of the extreme pairs to pass through it almost in totality.

Let us see how this effect is produced. "We shall take a pile in activity, and suppose that all the pairs of which it is composed, are so exactly similar in every respect, that the free electricity on each of them, has the same intensity. Let *b*, be a pair in the pile taken at hazard, and disposed in such a manner, that its *zinc* is immersed in the same liquid as the copper of the pair *a*, which precedes it; and its copper in the same liquid as the zinc of the pair *c*, which follows it. The chemical action of the liquid upon the zinc of the pair *b*, develops in it a certain quantity of electricity; the portion of this electricity, which does not undergo immediate recomposition, remains free, and the same for all the pairs, they being similar and symmetrically disposed, with relation to each other. According to this, the positive electricity of *b*, developed by chemical action, in the liquid in which the copper of *a* is immersed, neutralizes the negative electricity of this *latter pair,* which is equal to it. In the same manner, the negative electricity of *b*, which by chemical action is carried to the zinc, and thence to the copper, in contact with the zinc, neutralizes the positive electricity of *c*, which also is perfectly equal to it. There remains then an excess of free positive electricity, in the liquid in which the zinc of *a* is immersed; and an excess of free negative electricity, perfectly equal upon the copper of *c*. But these free electricities are neutralized by the equal and opposite electricities of the following pairs, with regard to which, we may reason in the same manner as for the pairs *a*, *b*, *c*. Thence there results an excess of free positive electricity at the extremity of the pile, at the side of *a*; and an exactly equal excess of negative electricity, at the extremity, situated at the side of *b*. Such is found to be the fact, if a communication be established between each of the extremities, and an electroscope; and if they be united by a conductor, the two excesses of free electricity are collected together and form the current. The intensity of this current as experiment has proved, ought to be perfectly equal to that of the current, which is established in the pile itself, between all the pairs."

M. De la Rive next proceeds to show how it happens, that though the quantity of free electricity developed upon each pair of the pile be frequently, not *mathematically* the same, yet the current which traverses a conductor, uniting the two extremities, is still *mathematically* equal to that which traverses each of the pairs.

To establish this important result, instead of soldering the zinc and copper of the same pair to each other, an independent conductor must be fixed to each. By means of these two conductors, a metallic communication is established between the two metals of the pair, by the intervention of one of the wires of a double galvanometer, the second wire of which serves as conductor to the current of a second pair of the same pile, or to effect a communication between the two poles.

If these two currents, are carefully made to pass in contrary directions, in each of the wires of the galvanometer, their action on the needle will be always found absolutely null, provided they are mathematically equal. This equality is easily explained. Take the most feeble pair in the pile; let *b* be the pair; the positive electricity disengaged by *b*, cannot neutralize all the negative of *a;* there will remain then, in the copper of *a*, an excess of negative electricity, which will retain, by neutralizing it, an equal quantity of positive; the result will be, that *a*, though much stronger than *b*, can only set at liberty a quantity of positive electricity, equal to that of *b*. It appears from this analysis, that the current of each pair, and consequently the current of the whole pile, should be equal to the current produced by the *weakest pair*. Now experiment fully proves, that if a feeble pair is introduced into a pile composed of energetic pairs, the immediate result is a considerable diminution in the force of the current of the pile, and consequently of the current of each of the other pairs. But this reduction is never sufficient to render this current equal to that, which would be developed by the pair, introduced in an isolated state. Indeed, any pair whatever, necessarily produces a greater quantity of electricity, when it is in the circuit, than when it is isolated. From these valuable remarks, we see how necessary it is, in the construction of compound voltaic batteries, to prepare plates as similar as possible, both in size, and quality of metal; for of how many pairs soever the arrangement may consist, and how perfect and alike soever all the other pairs may be, the introduction of one smaller, or faulty pair, will inevitably reduce the power of the battery to that, which would result from an equal number of pairs of plates, of the size and condition of the feeble pair.

I must now bring this lecture to a close, and with it the subject of galvanism. I have endeavoured to give as concise and as interesting an account of its present state, as my limits will allow, and as its reformed condition will admit. I say its ***reformed condition***, because there is no branch of physical science, which has undergone such a thorough revision, attended with such success, in the last few years, as galvanism. Its importance and interest have also been much increased lately, by the close connection which has been found to exist, between it and another science, that of magnetism; and from which a new branch of physics has sprung, that of electro-magnetism. This analogy and connection we shall see as we proceed; but I must first direct your attention to magnetism alone.

LECTURE V.

ON MAGNETISM.

ALTHOUGH the attractive power of the loadstone appears to have been known in times of very remote antiquity, and its properties studied even during the dark ages, yet its *directive* power, and that of a needle touched or rubbed with it, seems to be the discovery of modern times. In an old French poem, called La Bible Guyot, which is contained in a curious quarto manuscript of the thirteenth century, still existing in the Royal Library at Paris, and in several other authors, there are notices which prove that the mariner's compass was known in the twelfth century; and Cardinal James de Vitri, who flourished about the year 1200, mentions the magnetic needle in his history of Jerusalem; and he adds, that it was of indispensable utility to those who travelled by sea.

A Neapolitan named Flavio Gioia, who lived in the thirteenth century, has been regarded by many as the inventer of the compass. Dr. Gilbert affirms that Paulus Venetus brought the compass from China to *Italy in* 1260; and Ludi Vestomannus asserts, that about 1500, he saw a pilot in the East Indies direct his course by a magnetic needle like those now in use. The variation of the needle was discovered two hundred years before the time of Columbus, but the *variation of the variation*, that is, the fact that the variation was not a constant quantity, but varied in different latitudes, was first noticed by the discoverer of America, as appears from the following extract from Irving's Life and Voyages of Columbus, vol. 1, p. 201. "On the 13th of September, 1492, he perceived about night-fall, that the needle instead of pointing to the north-star, varied but half a point, or between five and six degrees, to the north-west, and still more on the following morning. Struck with this circumstance, he observed it attentively for three days, and found that the variation increased as he advanced. He at first made no mention of this phenomenon, knowing how ready his people were to take alarm; but it soon attracted the attention of the pilots, and filled them with consternation. It seemed as if the laws of nature were changing as they advanced, and that they were entering into another world, subject to unknown influences. They apprehended that the compass was about to lose its mysterious virtues; and, without this guide, what was to become of them in a vast and trackless ocean? Columbus tasked his science and ingenuity for reasons with which to allay their terrors. He told them that the direction of the needle was not to the polar star, but to some fixed and invisible point. The variation was not caused by any failing in the compass, which like the other heavenly bodies had its changes and revolutions, and every day described a circle round the pole. The high opinion that the pilots entertained of Columbus, as a profound astronomer, gave weight to his theory, and their alarm subsided."

That ferruginous substances always possess a greater or less degree of magnetism, has long been known. One Julius Cæsar, a surgeon of Rimini, first observed the conversion of iron into a magnet. In 1590 he noticed this effect on a bar of iron, which had supported a piece of brick work, on the top of a tower of the church of St. Augustin. The very same fact was observed about 1630, by Gassendi, on the cross of the church of St. John, at Aix, which had fallen down in consequence of having been struck with lightning. He found the foot of it wasted with rust, and possessing all the properties of a loadstone.

In the year 1600, Dr. Gilbert of Colchester, published a work, entitled "Physiologia Nova, seu Tractatus de Magneti et corporibus Magneticis," which contains almost all the information concerning magnetism, which was known during the two following centuries. He regarded the earth as acting on a magnetized bar, and upon iron, like a magnet, the directive power of the needle being produced by the action of magnetism of a contrary kind to that which exists at the extremity of the needle directed towards the pole of the globe. He gave the the name of *pole*, to the extremities of the needle, which pointed towards the poles of the earth, conformably to his views of terrestrial magnetism; calling the extremity that pointed towards the north, the south pole of the needle, and that which pointed to the south, the north pole.

Newton, Huygens, and Hooke, with some of the other philosophers who flourished about the end of the seventeenth century, were occupied to a certain extent with the subject of magnetism. Some of their observations and discoveries are referred to in a manuscript volume of notes and commentaries, written by David Gregory, in 1693, in a copy of Newton's Principia, and used by Newton in improving his second edition. Newton had supposed that the law of magnetic action approaches to the inverse triplicate ratio of the distance; but Gregory did not adopt this opinion, and invalidates the arguments that were used in its support. Newton committed another mistake in asserting that red hot iron has no magnetic property.

In 1683, Dr. Edmund Halley published his theory of magnetism. He regarded the earth's magnetism, as caused by four poles of attraction, two of them near each pole of the earth: and he supposes, "that in those parts of the world, that lie nearly adjacent to any one of these magnetic poles, the needle is governed thereby, the nearest pole being always predominant over that more remote." He supposes that the magnetic pole, which was, in his time, nearest Britain, was situated near the meridian of the land's end, and not above 7° from the north pole; the other north magnetic pole being in the meridian of California, and about 15° from the north pole of the earth. He placed one of the two south poles about 16° from the south pole of the globe, and 95° west from London; and the other, or the most powerful of the four, about 20° from the south pole, and 120° east of London.

In order to account for the change in the variation, Dr. Halley, some years afterwards, added to these reasonable suppositions, the very extraordinary one, that our globe was a hollow shell, and that within it, a solid globe revolved, in nearly the same time as the outer one, and about the same centre of gravity, and with a fluid medium between them. To this inner globe, he assigned two magnetic poles, and to the outer one, other two: and he conceived the change in the variation of the needle, to be caused by a want of coincidence in the times of rotation of the inner globe, and the external shell. "Now supposing," says he, "such an external sphere, having such a motion, we may solve the two great difficulties in every former hypothesis: for, if this exterior shell of the earth, be a magnet, having its poles at a distance from the poles of diurnal rotation, and if the internal nucleus be likewise a magnet, having its poles in two other places, distant also from its axis, and these latter by a gradual and slow motion, change their places in respect of the external, we may then give a reasonable account of the four magnetic poles, as also of the changes of the needle's variation." From some reasons, which Dr. Halley then states, he concludes "that the two poles of the external globe, are fixed in the earth, and that if the needle were wholly governed by them, the variation would be always the same, with some little irregularities; but the internal sphere, having such a gradual translation of its poles, influences the needle, and directs it variously, according to the result of the attractive and directive power of each pole, and consequently there must be a period of revolution of this internal ball, after which the variation will return as before."

Mr. Graham, a celebrated mathematical instrument maker, in London, discovered in 1722, the daily variation of the needle. While the needle was advancing by a gradual motion to the westward, Mr. Graham found that its north extremity moved westward, during the early part of the day, and returned again in the evening, to the eastward, to the same position which it occupied in the morning, remaining nearly stationary during the night. Mr. Graham at first, ascribed these changes to defects in the form of his needles; but by numerous and careful observations, repeated under every variation of the weather, and of the heat and pressure of the atmosphere, he concluded that the daily variation was a regular phenomenon, of which he could not find the cause. It was generally a maximum, between ten o'clock, A. M., and four o'clock, P. M.; and a minimum, between six and seven o'clock, P. M. Between the sixth of February, and the twelfth of May, 1722, he made a thousand observations in the same place, from which he found, that the greatest westerly variation, was 14°45″, and the least 13°50″: but in general, it varied between 14°35″ and 14°, giving 35″ for the amount of the daily variation.

Various speculations respecting the cause of the phenomena of magnetism, had been hazarded by different authors: but it was reserved for M. Epinus to devise a rational hypothesis, which embraced and explained almost all the phenomena, which had been observed by previous authors. This hypothesis, which he has explained at great length, in his "Tentamen Theoriæ Electricitatis et magnetismi," published in 1759, may be stated in the following manner:—

I.—In all magnetic bodies, there exists a substance which may be called the magnetic fluid, whose particles repel each other with a force inversely as the distance.

2.—The particles of this fluid attract the particles of iron, and are attracted by them in return, with a similar force.

3.—The particles of iron repel each other according to the same law.

4.—The magnetic fluid moves through the pores of iron, and soft steel, with very little obstruction; but its motion is more and more obstructed as the steel increases in hardness or temper, and it moves with the greatest difficulty in hard tempered steel, and the ores of iron.

The method of making artificial magnets, which was practised by the philosophers of the seventeenth century, was a very simple, but a very inefficacious one. It consisted in merely rubbing the steel bar to be magnetised upon one of the poles of a natural or artificial magnet, in a direction at right angles to the line joining the poles of the magnet. Towards the middle of the eighteenth century, however, the art of making artificial magnets had excited general attention; and it is to Dr. Gowin Knight, an English physician, that we are indebted for the discovery of a method of making powerful magnets. This method he kept secret from the public, but it was afterwards published by Dr. Wilson. Duhamel, Canton, Michell, Antheaume, Savery, Epinus, Robison, Coulomb, Biot, Scoresby, and others, made various improvements on this art; but for a detailed account of their numerous experiments, I must refer you to the article on magnetism, drawn up by Sir David Brewster, for the *seventh edition* of the Encyclopœdia Britannica, from which this short sketch of the history of magnetism, is in a great measure, compiled.

One of the ablest cultivators of the science of magnetism, was the celebrated Coulomb, who, by the application of the principle of torsion, first used by Michell, determined the correct law of magnetic attraction and repulsion. Provided with such a delicate instrument as the torsion balance, this philosopher was enabled to apply it with singular advantage, to almost every branch of science. His first object was to determine the law, according to which, magnetism is distributed to a magnetic bar. It was of course well known, that the magnetism, in the middle of a bar, was imperceptible, and that it increased according to a regular law, and with great rapidity, towards each of the poles. By suspending a small proof needle, with a silk fibre, and causing it to oscillate horizontally opposite different points of a magnetic bar, placed vertically, Coulomb computed the part of the effect, that was due to terrestrial magnetism, and the part that was due to the action of the bar; and in this way, he showed the extreme rapidity, with which magnetism is increased towards the poles.

In examining the distribution of electricity, in a circular plane, Coulomb found that the thickness of the electric stratum was almost constant from the centre, to within a very small distance of the circumference, when it increased all on a sudden with great rapidity, (as has been shown in a former lecture.) He conceived that a similar distribution of magnetism, took place in the transverse section of a magnetic bar; and by a series of nice experiments with the torsion balance, he found this to be the case, and established the important fact, that the magnetic power resides on the *surface* of iron bodies, and is entirely independent of their mass.

The effect of temperature on magnets, was another subject to which Coulomb directed his powerful mind; but he did not live to give an account of his experiments, which were published after his death, by his friend, M. Biot. Coulomb found that the magnetism of a bar, magnetized to saturation, diminished greatly by raising its temperature from 12° of Reaumur, to 680°; and that when a magnetic bar was tempered at 780°, 860°, and 950° of Reaumur, the development of its magnetism was gradually increased, being more than double at 900° of what it was at 780°. He found also that the directive force of the bar, reached its maximum, when it was tempered at a bright cherry red heat, at 900°; and that at a higher temperature the force diminished.

Coulomb made many valuable experiments on the best methods of making artificial magnets, and he subjected all the various processes that had previously been employed to the test of accurate measurement. His experiments on the best forms of magnetic needles are equally valuable; but the most interesting of his researches, and the last to which he devoted his great talents, were those which relate to the action of magnets upon all natural bodies. Hitherto, iron, steel, nickel, and cobalt, had been regarded as the only magnetic bodies; but in the year, 1802, Coulomb announced to the institute of France, that all bodies whatever are subject to the magnetic influence, even to such a degree as to be capable of accurate measurement. In order to determine if the phenomena were owing to particles of iron disseminated through the bodies, which he subjected to experiment; he tried a needle of silver, purified by cupellation, and another needle of silver alloyed with $\frac{1}{320}$th part of iron, and he found that the action of a magnet on the former, was four hundred and fifteen times less than upon the latter. Hence as he had previously shown that the forces exerted by magnets on needles, are proportional to the absolute quantities of iron which they contain, there will be four hundred and fifteen times less iron in the pure than in the impure silver; and since the latter contained $\frac{1}{820}$th part of its weight of iron, the first will contain $\frac{1}{415}$th part of $\frac{1}{320}$th, or $\frac{1}{132800}$th, or it will contain one hundred and thirty-two thousand, seven hundred and ninety-nine parts of pure silver, and one of iron, a quantity of alloy beyond the reach of chemical detection.

Amongst the scientific travellers who have contributed to our knowledge of terrestrial magnetism, Baron Alexander Humboldt was one of the most distinguished. Himself an accurate and scientific observer, and possessed of instruments and methods of research, he made numerous accurate observations on the dip and variation of the needle in various parts of the earth, and particularly near the magnetic equator; and by means of these valuable data, M. Biot was enabled to throw much light on the subject of terrestrial magnetism.

In the aerostatic ascent of M. M. Gay Lussac, and Biot, they were unable to detect any change in the intensity of terrestrial magnetism at the height of four thousand metres. Saussure, however, had found that the intensity was considerably less on the Col du

Géant than at Chamouni and Geneva; the difference in the levels of these places, being, in the one case, ten thousand and in the other seven thousand eight hundred feet; but his observations contradict his conclusions. M. Kupffer has more recently obtained a similar result, by observations on Mount Elbrouz; having found a decrease in intensity in rising four thousand five hundred feet above his first station; and he explains the result obtained by M. M. Gay Lussac and Biot, by supposing that an increase of intensity was produced by a diminution of temperature. Mr. Henwood, on the other hand, has made observations at the surface of Dolcoath mine, at one thousand three hundred and twenty feet beneath its surface, and on a hill, at seven hundred and ten feet above the level of the sea, without being able to detect any difference in the intensity. To the late Captain Foster we are indebted for many valuable observations on the magnetic intensity, made at Spitzbergen, and elsewhere. From these he concluded, that the diurnal change in the horizontal intensity, is principally, if not wholly, owing to a small change in the amount of the *dip*. The maximum took place at about 3hr. 30′ A. M., and the minimum at 2hr. 47′ P. M.; its greatest change amounting to $\frac{1}{83}$rd of its mean value. Captain Foster is of opinion, that these changes have the sun for their primary agent, and that his action is such as to produce a constant inflection of the pole towards the sun, during the twenty-four hours; an idea which had been previously stated by Mr. Christie.

About the year 1818, Professor Barlow, of Woolwich, turned his attention to the subject of magnetism, with a view, principally, of calculating the effect of ship's guns on the compass. In trying the effect of different iron balls, he was led to the curious facts—that there exists round every mass of iron, a great circle inclined to the horizon, at an angle, equal to the complement of the dip of the needle;—that the plane of this circle is a plane of no attraction upon a needle whose centre is in that plane;—that if we regard this circle as the magnetic equator, the tangent of the deviation of the needle from its north or south pole, will be proportional to the rectangle of the sign of the double latitude, and cosine of the longitude;—that when the distance of the needle is variable, the tangent of deviation will be reciprocally proportional to the cube of the distance, and that, all things else being the same, the tangent of deviation will be proportional to the cubes of the diameters of the balls, or shells, whatever be their masses, provided their thickness exceeds a certain quantity. Mr. Barlow was, from these discoveries, enabled to invent a most ingenious method of correcting the error of the compass, arising from the attraction of all the iron on board ships. This source of error had been noticed by Mr. Wales, Mr. Downie in 1794, and by Captain Flinders; but it is to Mr. Bain, that we owe the distinct establishment and explanation of this source of error. As a hollow shell of iron, about four pounds in weight, acts as powerfully at the same distance as a solid iron ball of two hundred pounds weight, Mr. Barlow happily conceived that a plate of five or six pounds weight might be made to represent and counteract the amount of the attraction of all the iron on board a vessel, and therefore leave the needle as free to obey the action of terrestrial magnetism as if there were no iron in the ship at all. After this ingenious contrivance had been submitted to the admiralty, it was tried in every part of the world; and even in the regions which surround the magnetic pole, where the compass becomes useless, it never failed to indicate the true magnetic direction, when the connecting plate was properly applied. "Such an invention as this," says Captain Parry, "so sound in principle, so easy in application, and so universally beneficial in practice, needs no testimony of mine to establish its merits; but when I consider the many anxious days and sleepless nights, which the uselessness of the compass in these seas had formerly occasioned me, I really should have esteemed it a kind of personal ingratitude to Mr. Barlow, as well as great injustice to so memorable a discovery, not to have stated my opinion of its merits, under circumstances so well calculated to put them to a satisfactory trial." For this beautiful invention, the board of longitude conferred upon Mr. Barlow the highest reward of five hundred pounds; and the emperor of Russia, who was never inattentive to the interests of science, sent him a fine gold watch, and a rich dress chain, for the same contrivance.

The late Dr. Morichini, an eminent physician at Rome, first announced it as an experimental fact, that an unmagnetised needle could be rendered magnetic, by the action of the violet rays of the sun. His experiments were successfully repeated by Dr. Carpi, at Rome, and the Marquiss Ridolfi, at Florence: but M. d'Hombre Firmas, at Alais, in France, Professor Configliachi, of Pavia, and M. Bérard, of Montpellier, *failed* in obtaining decided magnetic effects from the violet rays. In 1814, Dr. Morichini exhibited the actual experiment to Sir Humphry Davy, and 1817, Dr. Carpi showed it to Professor Playfair. A few months after Sir Humphry witnessed the experiment, Sir David Brewster met him at Geneva, and learned from him the fact, that he had paid the most diligent attention to one of Morichini's experiments, and that he saw an unmagnetised needle rendered magnetic by violet light. The following account of the experiment, made by Dr. Carpi, was given to Sir David, by Professor Playfair:—"The violet light was obtained in the usual manner, by means of a common prism, and was collected into a focus by a lens of sufficient size. The needle was made of soft wire, and was found upon trial, to possess neither polarity, nor any power of attracting iron filings. It was fixed horizontally upon a support, by means of wax, and in such a direction, as to cut the magnetic meridian at right angles. The focus of violet rays, was carried slowly along the needle, proceeding from the centre, towards one of the extremities, care being taken, never to go back in the same direction, and never to touch the other half of the needle. At the end of half an hour after the needle was exposed to the action of the violet rays, it was carefully examined, and it had acquired neither polarity, nor any force of attraction: but after continuing the operation twenty-five minutes longer, when it was taken off and placed on its pivot, it traversed with great alacrity, and settled in the direction of the magnetical meridian, with the end over which the rays had passed turned to the north. It also attracted and suspended a fringe of iron filings. The extremity of the needle that was exposed to the action of the violet rays, repelled the north pole of a compass needle. This effect was so distinctly marked, as to leave no doubt in the minds of any who were present, that the needle had received its magnetism from the action of the violet rays." In this state of the subject, Mrs. Somerville made some simple and well conducted experiments, which seemed to set the question at rest, from the distinct and decided character of the results. A sewing needle, an inch long, and devoid of magnetism, had one half of it covered with paper, and the other exposed to the violet rays of the spectrum, five feet distant from the prism. In two hours it acquired magnetism, the exposed end exhibiting north polarity. The *indigo* rays produced an equal effect, and the *blue* and the *green* the same in a less degree. The yellow, orange, and red rays, had no effect even after three day's exposure to their action. Pieces of blue watch spring, received a higher magnetism. When the sun's light fell upon the exposed end through blue-coloured glasses, or through *blue* or *green* riband, the same magnetic effects were produced. The experiments of Mr. Christie, an account of which was read to the Royal Society, a short time before Mrs. Somerville's, confirmed her results to a certain degree, by a different mode of observation. The general opinion seems, however, now to be, that light does not exercise any decided effect in producing magnetism. The experiments of M. M. P. Ries and Moser, were made with needles, both polished and oxidated, and also with wires half polished; and polarized as well as common light, was made to fall on them in a concentrated state, but no decided effect upon their number of *oscillations* could be observed; and they state that they think themselves justly entitled, *to reject totally, a discovery, which for seventeen years, has at different times, disturbed science.*

A valuable series of observations, on the influence of the aurora borealis on the magnetic needle, was made by Dr. Dalton, at Kendal and Keswick, during seven years, from May, 1786, to May, 1793, and has been published in his meteorological observations and essays, which appeared in 1793. During these observations, he noticed the effect they produced on the magnetic needle, and he was thus led to study the phenomena of the aurora, and to establish, beyond a doubt, the relation of all its phenomena, to the magnetic poles and equator. In some cases however, Dr. Dalton did not observe any perceptible disturbance of the needle.

Professor Hanstein, who has been extensively occupied with the subject of magnetism, observes, that large extraordinary movements of the needle, in which it traverses frequently, with a shivering motion, an arc of several degrees on both sides of its usual position, are seldom, perhaps never exhibited, unless when the aurora borealis is visible, and that this disturbance of the needle, seems to operate at the same time, in places the most widely separate.

From an extensive series of accurate observations, made by M. Arago, at Paris, since 1818, the needle was almost invariably found to be affected by auroræ, that were seen in Scotland; and so striking was the connection between the two classes of facts, that the existence of the aurora could be inferred from the derangements of the needle. M. Arago has likewise discovered, that early in the morning, often ten or twelve hours before the aurora is developed in a very *distant place, its* appearance is announced by a particular form of the curve, which exhibits the diurnal variation of the needle, that is, by the value of the morning and evening maxima of elongation.

During the late journey of Captain Back to the polar regions, in 1833, 1834, and 1835, he found that the needle was generally affected by the aurora; and on one occasion the deviation which it produced was 8°; he repeatedly observed that when the aurora was concentrated in individual beams, the needle was powerfully affected; but that it generally returned to its mean position, when the aurora became generally diffused. On several occasions, the needle was restless, and exhibited the vibrating action, produced by the aurora, when this motion was not visible; and Captain Back states that he could not account for this, except by supposing the invisible presence of the aurora in full day.

The only metals which were supposed to have a distinct and decided power, and were therefore called magnetic metals, are iron, cobalt, and nickel. Mr. David Lyon has lately endeavoured to show that these metals resemble one another, not only in their principal qualities, but in the numerical values of their qualities: and he adds, that whilst these three magnetic substances, have the values above referred to, near each other, there are no other substances in which the same values come very near, or fall within those of the three magnetic substances. The values to which Mr. Lyon alludes, are the following:—

	Specific gravity.	Atomic weight.	Atoms contained in a given space.
Nickel	8·27	739·51	1118
Iron	7·21	678·43	1062
Cobalt	7·8	738	1057

These speculations, though ingenious, and deserving of attention, have been recently overturned by some observations of Professor Faraday. "Cobalt and Chromium," says he, "are said to be both magnetic metals. I cannot find that either of them is so, in its pure state, at any temperatures. When the property was present in specimens, supposed to be pure, I have traced it to iron or nickel."

Mr. Faraday thinks that all metals are magnetic, in the same manner as iron, though not at common temperatures, or under ordinary circumstances. He does not allude to a feeble magnetism, uncertain in its existence and source, but to a distinct and decided power, such as that possessed by iron and nickel; and his impression is, that there is a certain temperature for each metal (well known in the case of iron, beneath which it is magnetic, and above which it loses all power), and that there is some relation between this *point* of temperature, and the intensity of the magnetic force, which the body, when reduced beneath it can acquire, iron and nickel would then be no more exceptions from the metals in regard to magnetism, than mercury is in regard to liquefaction.

M. Pouillet, on the other hand, thinks that there are five simple magnetic bodies, viz., iron, manganese, nickel, cobalt, and chrome; and in consequence of having observed some remarkable analogies, between the distance of the atoms of bodies, and their magnetic properties, he was led to suppose that the magnetic limit of different bodies ought to be found at very different temperatures. "I have indeed," says he, "demonstrated by experiment, first, that cobalt never ceases to be magnetic, or rather that its magnetic limit is at a temperature, higher than the brightest white heat; second, that chrome has its magnetic limit a little below the temperature of dark blood-red heat; third, that nickel has its magnetic limit about 350° centigrade, nearly at the melting point of zinc; and fourth, that manganese has its magnetic limit at the temperature of from 20° to 25° below zero. Experiments on these five magnetic bodies, seem to prove first, that heat acts upon magnetism only, in consequence of the greater or less distance which it occasions, between the atoms of bodies; and second, that all bodies would become magnetic, if we could, by any action whatever, make their atoms approach within a suitable distance."

Having thus given a short sketch of the history and progress of magnetism, I shall proceed to lay before you, some of its general facts and principles.

The native magnet, or natural loadstone, is an ore of iron, consisting chiefly of the two oxides of that metal, together with a small proportion of quartz and alumina. It is usually of a dark grey hue, and has a dull metallic lustre. It is found in considerable masses in the iron mines of Sweden and Norway, and also in different parts of Arabia, China, Siam, and the Philippine Islands. Small loadstones have occasionally been met with among the iron ores of England. The smallest loadstones have generally a greater attractive power in proportion to their size, than larger ones. They have been found of such a strength, that though weighing only about twenty-five grains, they could lift a piece of iron *forty-five* times heavier than themselves. Sir Isaac Newton had a small specimen, set in a ring, which was capable of lifting seven hundred and forty-six grains of iron, or two hundred and fifty times its own weight: and it is stated by Cavallo, that he has seen a loadstone, which weighed only six grains and a half, which lifted a weight of three hundred grains.

If we immerse a natural loadstone, no matter of what shape, in a quantity of clean iron filings, we shall find that there are two points exactly opposite each other, on which the filings are accumulated more abundantly than on any other place; these are called its poles; and if we balance a small needle of iron on a pivot, and bring it near either of these poles, we shall find that it will be attracted towards it; or, conversely, if we suspend the loadstone by a fine fibre, and bring into the vicinity of its poles, a piece of soft iron, it will be drawn towards the iron; a reciprocal attraction is exerted between them, action and re-action being equal and opposite.

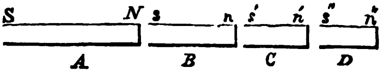
When a piece of steel has been rendered magnetic, it exhibits the same properties as the natural loadstone; and since we are in possession of a variety of methods of communicating to it this state, the artificial magnet is always employed in experimental investigations. I shall describe some of the most approved methods of magnetising iron presently, in the mean time, I shall only observe, that for the exhibition of the experiments I shall first have to allude to, the following simple and ready method, will be found amply sufficient for communicating to small bars of steel the requisite degree of magnetism.

Let a straight bar of hard tempered steel, be held in a position slightly inclined to the perpendicular, the lower end deviating to the north, and struck several hard blows with a hammer, it will be found to have acquired by this process, all the properties of a magnet.

If a bar which has been thus treated, is supported on a pivot, in such a manner as to have entire freedom of motion in a horizontal plane, and if all bodies of a ferruginous nature are removed from its vicinity, it will, after a few oscillations, take up a position nearly north and south; and if it is disturbed from this position, and placed in any other, it will not remain there, but as soon as it is at liberty to move, it will resume its former position. It will also possess the power of communicating magnetism to hard steel *permanently*, and to soft iron *temporarily*, the degree of strength of course depending on its own power; and with respect to the steel, to the time which it is suspended. If two magnetised bars are poised and placed in different positions respecting each other, it will be found, that in some cases they appear to be attracted towards each other, while in others, they manifest a mutual repulsion. This however, does not happen capriciously; the two north poles and the two south poles invariably repel each other, but the north pole of one magnet always attracts, and is of course, attracted by the south pole of the other.

In order to communicate magnetism from a natural or artificial magnet, to unmagnetised iron or steel, it is not necessary that the two bodies should be in contact. The communication is effected as perfectly, though more feebly, when the bodies are separated by space. Thus, in *Fig.* 54, if the *north* pole of an artificial steel

Fig. 54.

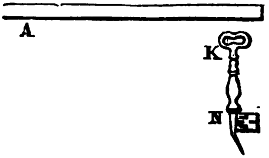


magnet A, is placed near the extremity S, of a piece of soft iron B, the end *s* will instantly acquire the properties of a *south* pole, and the opposite end *n*, those of a north pole. The opposite poles would have been produced at *n* and *s*, if the south pole *s*, of the magnet A, had been placed near the iron B.

In like manner, the iron B, though only temporarily magnetic, will render another piece of iron C, and this again, another piece D, temporarily magnetic, north and south poles being produced at *n*′, *s*′, and *n*,″ *s*″.

Here we cannot fail observing the pointed analogy which subsists between the phenomena of magnetic attraction and repulsion, and those of electricity. In both there exists the same character of double agencies of opposite kind, capable, when separate, of acting with great energy, and being, when combined together, perfectly neutralized, and exhibiting no signs of activity. As there are two electrical, so there are also two magnetic powers, and both sets of phenomena are governed by the same characteristic laws. So also in the last experiment, the magnetism inherent in B, C, D, is said to be *induced* by the presence of the real magnet A, and the phenomena are exactly analagous to the communication of electricity to unelectrified bodies by induction, the positive state inducing the negative, and the negative the positive, in the parts of a conductor placed in a state of insulation near an electrified body.

Fig. 55.



A simple experiment will satisfactorily show that soft iron possesses magnetic properties, while it remains in the vicinity of a magnet. Let A, *Fig. 55*, be a magnet, and K a key held either horizontally near one of its poles, or near its lower edge; then if another light piece of iron, such as a small nail be applied to the other end of the key, the nail will hang from the key, and will continue to do so, while the magnet is slowly withdrawn, but when it has been removed beyond a certain distance, the nail will drop from the key, because the magnetism induced on the key becomes at that distance, too weak to support the weight of the nail. That this is the real cause of its falling off, may be proved, by taking a still lighter fragment of iron, such as a piece of very slender wire, and applying it to the key. The magnetism of the key will still be sufficiently strong to support the wire, though it cannot the nail, and it will continue to support it, even when the magnet is yet further removed; it at length however drops off.

If the key is held above a portion of iron filings, they will not be attracted by it, but if the magnet is then brought near the ring of the key, as in the figures, the iron filings will instantly start up, and be attracted by the key.

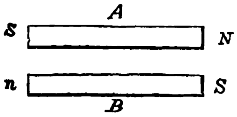
It has been observed, that in all cases where a magnet attracts iron, a re-action takes place, the iron attracting the magnet; it is the same with a bar of iron on which magnetism has been induced. It re-acts upon the magnet, which induces its magnetism, and increases its magnetic intensity. Hence we derive a distinct explanation of the remarkable facts, that a magnet has its power increased by having a bar of iron placed in contact with one of its poles, and that we can gradually add more weight to that which is carried by the magnet, provided we make the addition slowly, and in small quantities, the power of the magnet being increased by the re-action of each separate piece of iron that it is made to carry.

These facts enable us to explain the phenomena of magnetic attraction and repulsion. The magnet attracts a piece of iron, by inducing an opposite polarity at the end in contact with it, and the two opposite principles attract each other. In like manner the north pole of one magnet attracts the south pole of the other, and the north and south poles repel each other, in consequence of the attraction and repulsion of the opposite and similar principles. The attraction of iron filings is explained in the same way. The particle of iron next the magnet has magnetism induced on it, and it becomes a minute magnet, like B, *Fig.* 54; this particle again makes the next particle a magnet, like C, and so on, the opposite polarity in each particle of the filings attracting one another, as if they were real magnets.

In comparing the amount of the *attractive* force of two *dissimilar* poles of two magnets, with the amount of the *repulsive* force of the two similar poles, it has been found that the former force is considerably greater than the latter. This result is a necessary consequence of the inductive process above described. When the two attracting poles are in contact, each magnet tends to increase the power of the other, by developing the opposite magnetic states in the adjacent halves, and thus increasing their mutual attraction. But when the two repelling poles are brought into contact, the action of each half brought into contact, has a tendency to develop in that half, a magnetism opposite to that which it really possesses, and thus to diminish the two similar principles, and weaken their repulsive power. This injurious influence of opposite poles upon the repulsive power of the magnets in action, is well exhibited when one of the magnets is very powerful and the other very weak. When the two similar poles are held at a moderate distance, a repulsion is distinctly exhibited; but when they are brought into contact, the stronger *attracts* the weaker magnet, an effect which is produced by its actually destroying the similar weak magnetism in the half next to it, and inducing in that half the opposite magnetism, which of course occasions attraction.

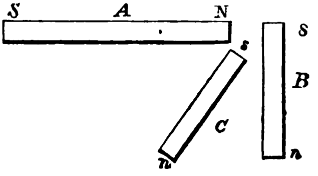
The most favourable position for the bars receiving and sustaining magnetism, is that of parallelism, for in this position, the induced magnetism of magnet A, *Fig.* 56, is the most powerful. Let us first suppose the bars arranged as in *Fig.* 57, the pole, N, of the magnet, A, acts favourably in inducing *south* polar magnetism in *n*, and north polar at *s*; but it is evident, that the remote pole, S, must tend to weaken the inductive force of N, by inducing, though in a feeble degree, north polar magnetism at *n*, and south polar at *s*.

Fig. 56.



If the soft iron, B, be placed, as in *Fig.* 57, the induced magnetism will be nearly as strong as before, the greater proximity of N, tending to produce south polar magnetism in *n*, being

Fig. 57.

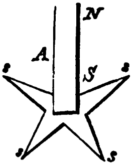


compensated for by the increased proximity of *s*, tending to produce north polar magnetism in *n*. In the inclined position C, the induced magnetism is still stronger, as *s* acts more powerfully upon *n*; and when the two bars are parallel, the inductive power is of course at its maximum.

If a magnetised steel bar be placed with its north pole, opposite the middle of a soft iron bar, the effect will be to induce upon it two north poles at the extremities, and a south pole in the centre: and so also if the soft iron bar be placed between two magnets, whose north poles are nearest the bar, these north poles will tend to produce two south poles at the extremities, and consequently a northern polarity in the middle.

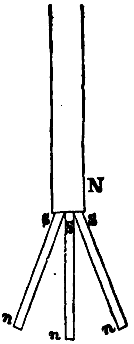
In like manner a piece of soft iron, *ss*, *ss*, *Fig.* 58, of the form of a cross, will have south poles at *s*, *s*, *s*, *s*, if the south pole of the magnet A, be placed on or near its centre, as it may be conceived to consist of two bars, *ss*, *ss*. For the same reason, if a circular piece of soft iron be substituted in place of the cross, and the south pole of the magnet placed on or near its centre, that centre will be a north pole, and every part of the circumference will have a southern polarity.

Fig. 58.



A very instructive experiment, founded on magnetic induction, is exhibited in *Fig.* 59, where several soft iron wires are suspended from the north pole of a magnet. Each of the ends becomes a south pole by induction, from the action of the north, and consequently the lower ends, north poles. The south poles have a natural tendency to repel each other, but are

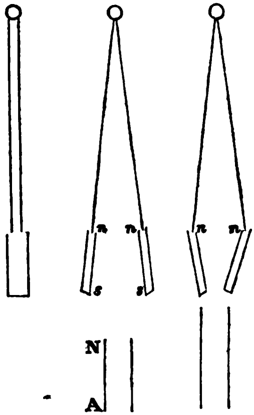
Fig. 59.



prevented from yielding to their repulsive forces, in consequence of their strong adhesion to the north pole, N. The north poles, *n*, *n*, *n*, are however, free from this restraint, and exhibit their mutual repulsion, by diverging, as shown in the figure. Hence we see the reason why rows of iron filings, adhering to each other, when attracted by a magnet, keep separate from each other by the repulsive forces of the similar poles.

In the following experiment of Cavallo, the repulsion of the poles is well illustrated. Let two short pieces of iron wire, *Fig*. 60, be each fastened to a thread, the threads being joined at their other ends and formed into a loop, by which they are to be suspended from a hook, so as to have full liberty to move. On bringing the pole of a magnet, the north for instance, at a certain distance below the wires, it will occasion them to recede from each other, as shown in *Fig*. 60, indicating the repulsion which takes place between the adjacent ends of the wires, in consequence of their being similarly affected by the *inductive* power of the magnet, the lower ends of both

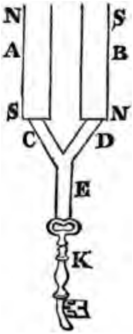
Fig. 60.



being rendered south poles, and the upper north poles. This divergency of the wires will continue to increase until the magnet has approached to a certain limit; but if the magnet be brought nearer than this limit, its own attractive force becomes so strong as to overpower the repulsion that exists between the lower ends of the wires, and therefore brings them nearer to each other, as shown in *Fig.* 60, while the repulsion of the upper ends, *nn*, still continues to manifest itself, by keeping them remote from one another. On removing the magnet entirely, the wires immediately collapse, their magnetism being only of a transitory nature. But if the same experiment be made with sewing needles, instead of soft iron wires, the needles will often continue to repel each other, after the removal of the magnet, having acquired some degree of permanent magnetism, by the circumstances in which they have been placed.

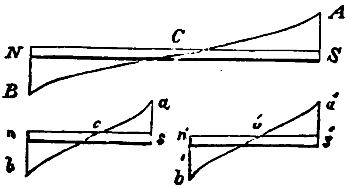
The neutralization or destruction of induced magnetism by two equal and opposite magnetic actions, is shown by the following experiment of Dr. Robinson. If we take a forked piece of iron, C, D, E, *Fig.* 61, and suspend it by the branch D, from the north pole of a magnet, B, it will be magnetised by induction, and will carry a key at its lower end E, which will be a north pole. If we now apply to the other branch C, the south pole S, of another and equal magnet A, the key will instantly drop off. This obviously arises from the south pole S, inducing a south pole at E, which either destroys or neutralizes the north polar magnetism previously induced by N.

Fig. 61.



We have seen the close analogy which exists between the phenomena of electricity and magnetism, as far as relates to the law of action and the influence of induction; but beyond this point it fails us entirely. No natural or artificial magnet has ever been seen with *only one pole*, or one kind of magnetism; electricity on the other hand, whether positive or negative, is not only capable of being excited by induction, but may be actually transferred from one body to another. A body may without difficulty, be electrified positively or negatively, as has been shown in a former lecture; but with magnetism there is never any transfer of properties, but only the excitation of those which were already inherent on the body operated on. It became therefore interesting to examine experimentally the distribution of magnetism in a part of a magnet, cut from its north or south extremity. The experiment has been often made, both by cutting it through at the middle or neutral point, or by cutting or breaking off a portion from the end of it. If N, S, *Fig.* 62, be a magnet, N, its north, and S, its south pole, and A, C, B, the curve representing the intensity of its magnetism; then, if we cut it through the middle, C, each half, *n s*, *n′ s′*, will be a complete magnet, with a north pole at *n*, and a south pole at *s*, and their neutral points at *c*, *c′*; the curves *a c b*, *a′ c′ b′*, representing the distribution of their north and *south polar* magnetism, being similar to the curve

Fig. 62.



A C B, of the large magnet of which they are halves.

This curious experiment is due to Epinus, and when he first made it, he did not divide the magnet in two, but he set two steel bars end to end, and magnetisep them as one magnet, so that this compound magnet had its magnetism distributed as in a single bar, N S, *Fig*. 62. He then separated them and found that each bar was a perfect magnet, with two poles. To insure success in this experiment, the united ends of the bars should be ground together, so as to be kept in perfect contact, and preserved in this state by a powerful pressure, during the time that they are magnetised.

Upon the separation of the magnets thus united, Epinus found that two poles were instantly developed in each half, but that the neutral points, *c c′*, *Fig*. 62, were nearer the interior poles, *s n′*, or, what is the same thing, nearer the original neutral point c, than to *n′* and *s*. In the space of about a quarter of an hour, it had, however, advanced nearer to the middle points, *c*, *c′*, and continued for some hours, sometimes for days, to advance to these points, which it finally reached, thus completing the regular distribution of the two opposite magnetisms.

We are indebted to M. Haldat, of Nancy, for the discovery of magnetic figures, analogous to those first produced with electricity, by M. Lichtenberg, and which may easily be exhibited. For this purpose he employs plates of steel, from eight to twelve inches square, and from one-twentieth to one-eight of an inch thick. The plates which he used were of that kind of steel which is used for the manufacture of cuirasses; so that it did not require to be tempered, being sufficiently hard to preserve the magnetism communicated to it. Figures of any kind may be traced on the surface of the steel plate, either by one magnet, or by several combined, and the best form for this purpose is that in which the poles are rounded. In this way we may write on a steel plate the name of a friend, or sketch a flower, or a figure, with the extremity of a magnet. If it is the south pole that we use, all the traces that we make will have north polar magnetism, and if we shake steel filings on the plate out of a gauze bag, the filings will arrange themselves in the empty spaces between the lines traced by the pole of the magnet, and thus represent in vacant steel the name which has been written, or the flower or figure which has been sketched. "These figures," says M. Haldat, "have a perfect resemblance to those which are formed on the surface of non-magnetic plates, viz., wood, card, glass, or paper, under which a magnet is placed. The resemblance between the two sorts of figures, when the magnets and the parts magnetised have the same form, is not only exact in the whole figure, but likewise in the smallest details. The filings collect at the parts where the magnetism is most intense, and they arrange themselves in pencils and radii. These curves, and pencils, and rays, so similar at the two poles of the same magnet, have such a resemblance that they do not allow us to distinguish the two parts from one another."

In sifting the iron filings upon the steel plate, a gentle vibration of the plate, by tapping its edge with the ring of a small key, will assist the filings in taking their proper places; but we must avoid such vibrations, as will produce regular acoustic figures, unless we wish, as M. Haldat has found to be practicable, to unite the magnetic with the acoustic figures, which produces very interesting and varied forms.

In order to remove the magnetism from the steel plates, they may be heated over charcoal, till they become of the straw-coloured temperature; and to render the re-polishing of them unnecessary, M. Haldat tins them, and the temperature at which the tin melts, when it is required to efface the magnetism, indicates the necessary heat.

As the figures traced on the steel are nothing more than magnets of different forms, and are surrounded on all sides with a substance capable of acquiring the magnetism which may be developed by communication, we might expect, as M. Haldat remarks, that this means of communication between the opposite poles of the magnets would bring them into a neutral state. This, however, is not the case; and the portion of the metal which surrounds the magnetic figure, performs the part of the *armature* of a loadstone, and the magnetism is thus kept up.

The figures might be rendered permanent, by covering the steel plate, either with a gummy or balsamic solution, which will become hard by exposure to the air; or with a coating of some easily melted substance which becomes fixed at ordinary temperatures. If we sift the iron filings on the steel plate when covered with such a fluid, the filings will take their magnetic position round the traced lines, and will become fixed by the induration or solidification of the fluid coating.

For a long time *iron* was regarded as the only magnetic metal, for though other substances were found to possess the property of acting and of being acted upon as a magnet, it was imagined that such effects were rather the result of the small quantity of iron entering into their composition, than to the magnetism residing in the proper substance of the body.

A series of careful experiments were made by Cavallo, on the magnetism of *brass* when hammered. He found that this compound, whether old or new, was made magnetic, when placed between two pieces of card, and hammered, either on an anvil by a hammer, or between two flints; he observes "It appears that the property of becoming magnetic in brass, by hammering, is rather owing to some peculiar configuration of its parts, than to any admixture of iron; which is confirmed still further, by observing that Dutch plate brass, (which is made, not by melting the copper, but by keeping it at a strong degree of heat, whilst surrounded by *lapis calaminaris*,) also possesses that property; at least such was the case with all the pieces I tried. From this it follows that when brass is to be used for the construction of instruments wherein a magnetic needle is concerned, as dipping needles, variation compasses, &c., the brass should either be left quite soft, or it should be chosen of such a sort as will not be made magnetic by hammering, which sort, however, does not occur very frequently."

These suggestions of M. Cavallo were not attended to, as their importance deserved, and there is no doubt that considerable errors have arisen from their neglect. Many examples have recently occurred in which the errors were detected; and it is now the invariable practice of well informed instrument makers, to reject hammered brass bowls for compasses, and to use those *which* are cast and turned for the purpose.

The existence of magnetism in brass, while there was not the least trace of it, either in the copper or zinc of which it is composed, led philosophers to investigate the effects produced by the union of different metals, or by their combination with other substances. Iron itself is a simple chemical body. Steel is a combination of iron and carbon. The loadstone is a combination of iron and oxygen; and as no magnetism is found either in carbon or in oxygen, we are naturally led to believe, as M. Pouillett has remarked, that the magnetic fluid resides in the substance of the iron, and that it is carried with the atoms of that metal, into all the chemical combinations which they form; we may, therefore, expect to find magnetic properties in all ferruginous bodies, whether the iron be an accidental or a necessary ingredient; and indeed cast-iron, plumbago, and the oxides and sulphurets of iron exert a sensible action on the needle.

On the other hand, Dr. Matthew Young found that the smallest admixture of antimony was capable of destroying the polarity of iron; and M. Seebeck states that an alloy of one part of iron and four parts of antimony were so completely destitute of magnetic action, that even when put into rotation, it exerted no action on the magnetic needle. The magnetic qualities of nickel, (which stand next to iron in magnetic susceptibility, and which is usually found to possess considerable power,) are also destroyed by a mixture with it of other metals. Chevenix found that a very small portion of arsenic deprived a mass of nickel, that had previously exhibited a strong magnetic power, of the whole of its magnetism; and Dr. Seebeck found that an alloy of two parts of copper with one of nickel was entirely devoid of magnetism, and on this account he recommends it as well suited for the manufacture of compass boxes. On the other hand, Mr. Hatchett ascertained, that when a large proportion of carbon, or sulphur, or phosphorus, was combined with iron, the iron was enabled fully to receive and retain its magnetic properties; but he at the same time found that there was a limit, beyond which, an excess of any of these three substances, rendered the compound wholly incapable of receiving magnetism.

Animal and vegetable substances, after combination, are said to be attracted by the magnet. The flesh and particularly the blood are acted on more powerfully than other parts, and bone less powerfully. Burned vegetables have the same property, and also soot and atmospheric dust; and M. Cavallo has maintained that brisk chemical effervescences acted upon the magnetic needle.

In 1802, the supposition of universal magnetism was put to the test of rigorous experiment by Coulomb. He employed a glass receiver, from the top of which was suspended, by a silk fibre, the needle of the substance to be examined, about an inch long, and one-thirtieth thick. The receiver was then placed so as to enclose the opposite poles of two powerful bar magnets, each formed of four bars of steel tempered to a white heat, and the number of oscillations of the needle between these poles were noted. It was found that *all substances whatever, when formed into small needles, turned themselves in the direction of the poles of the magnets, and after a few oscillations, finally settled in that position.* When these bodies were *moved* a very little way out of their position of equilibrium, they immediately began to oscillate round it, the oscillations being always performed more rapidly in the presence of the magnets than when they were removed out of their influence. Gold, silver, brass, wood, and all substances, whether organic or inorganic, thus obey the power of magnets. Hence we cannot avoid the conclusion, either that all bodies are susceptible of magnetism, or that they contain minute quantities of iron, or other magnetic metals, which give them their susceptibility. Various other methods have been employed in developing magnetism in all bodies whatever, since the time of Coulomb, but I must refer you for an account of them to the excellent treatise on magnetism, drawn up for the Encyclopœdia Britannica, by Sir D. Brewster. Recently, the universal prevalence of magnetism, has been fully established by a beautiful discovery of M. Arago. This distinguished philosopher conceived the idea of studying the oscillations of a magnetic needle, when placed above or near any body whatever. Having suspended a magnetic needle above metal, or even water, and caused it to deviate a certain number of degrees from its position, it began when left to itself, to oscillate in arcs of less and less amplitude, as if it had been placed in a resisting medium; and what was peculiarly curious in these experiments, this diminution in the amplitude of the oscillations, did not alter the number of oscillations which were performed in a given time. Dr. Seebeck found, that in alloying magnetic with non-magnetic substances, *he formed compounds which exercised no action on the needle.* The alloys which had particularly this singular property, were those consisting of four parts of antimony, and one of iron, or two parts of copper, and one of nickel. In these cases the magnetism of the two ingredients must have been neutralized by their opposite actions.

In consequence of these experiments of M. Arago, which were announced at the sitting of the French Institute, on the 7th of March, 1825, philosophers in every part of Europe turned their attention to the development of magnetism by rotation. The most important results were obtained by Messrs. Babbage and Herschell. A horse-shoe magnet, which lifted twenty pounds, was made to revolve rapidly round its axis of symmetry, placed vertically with its poles uppermost. A circular disc of copper, six inches in diameter, and one-twenty-fourth of an inch thick, was suspended above the revolving magnet. As soon as the rotation of the magnet commenced, the copper began to turn in the same direction, at first slowly, but afterwards with an increased velocity. When the magnet was made to turn in an opposite direction, the disc of copper changed the direction of its motion also, and exhibited the same phenomena. Metallic plates ten inches in diameter, and half an inch thick, when interposed between the magnet and the copper disc, did not sensibly modify the results, as M. Arago had observed. Glass produced no effect, but a sheet of tinned plate iron diminished greatly the influence of the magnet, while two such plates almost destroyed it. They found also that a disc of copper, ten inches in diameter, and half an inch thick, and revolving with a velocity of seven revolutions in a second, did not communicate any motion to a similar disc freely suspended above it.

Messrs. Babbage and Herschell next sought to determine the effect produced by a solution of continuity in the metallic disc, upon which the revolving magnet acted. For this purpose a disc of lead twelve inches in diameter, and one-tenth of an inch thick, was suspended at a given distance from a horse-shoe magnet, revolving with the ordinary rapidity, first in its entire state, and afterwards in the state shown in the annexed figures, the black lines in the direction of the radii being the planes where the lead was cut through, *Fig*. 63, 64, 65, 66, 67. The accelerating forces,

Fig. 63.

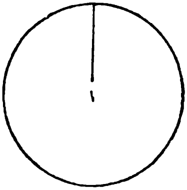


Fig. 64.

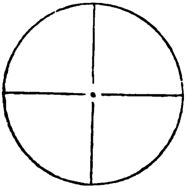


Fig. 65.

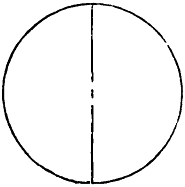


Fig. 66.

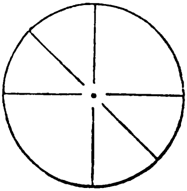
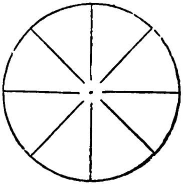


Fig. 67.



represented by $\frac{s}{t^2}$, where s is the number of the revolutions, and t, the time employed, are as follow:

Uncut disc	Disc as in *Fig.* 63.	Disc as in *Fig.* 64.	Disc as in *Fig.* 65.	Disc as in *Fig.* 66.	Disc as in *Fig.* 67,
1258.	1047.	913.	564.	432.	324.

Effects similar, but differing in degree, were obtained with other metals: with soft tinned iron, the cutting produced a very slight diminution of effect, while in copper the same operation reduced the accelerating force in the ratio of five to one.

They next tried the effect of filling up the cuts with different metals. A light upper disc suspended at a given distance above a revolving magnet, performed six revolutions in 54″ 8. When cut as in *Fig.* 67, its magnetic action was so weakened, that it took 121″ 3. to perform six revolutions; when the right open radial spaces were filled up with tin, its magnetic action was restored to such a degree that it made six revolutions in 57″ 3. This fact is very interesting, as tin has less than half the energy of copper.

M. Haldat made some very interesting experiments on this subject. He found that every needle, however weak was its magnetism, obeyed the action of the revolving disc; but that this action disappeared entirely when its polarity disappeared. He found it impossible to magnetise needles by the action of the revolving disc, however rapid; and in consequence of ascribing this effect to the want of coercive power, he employed discs of iron and steel, both soft and hardened.

A disc of soft iron acted with more energy than one of copper, and with the same velocity, it dragged the needle twice the distance that a disc of brass did. Iron strongly hammered acted like soft iron, and was unable to give polarity to a steel needle; but a disc of untempered steel, one-twenty-fifth of an inch thick, did not produce any appreciable effect on the magnetic needle, which after a few irregular oscillations, maintained its ordinary position of equilibrium. Hence he concluded that the force which acted upon it, was in the inverse ratio of the coercive force. M. Haldat also found that discs in a state of incandescence, exercised the same action as those at the ordinary temperature.

Mr. Snow Harris has recently shown that several substances not supposed to contain iron, have the power of intercepting the influence of a revolving magnet; contrary to the observations of Messrs. Babbage and Herschell. A cirçular magnetic disc being delicately balanced on a fine central point by means of a rim of lead, was put into a state of rotation on a small agate cup, at the rate of six hundred revolutions in a minute; and a light ring of tinned iron also finely balanced on a central pivot was placed immediately over it at about four inches distant, by means of a thin plate of glass, on which its pivot rested. When the ring of tinned iron began to move slowly on its pivot by the influence of the magnet revolving below, a large mass of *copper* about *three* inches thick, and consisting of plates a foot square, was carefully interposed between the net and the iron ring. The interposition of the copper soon sensibly diminished the motion of the iron disc, and at length *arrested it altogether*. On again withdrawing the copper, the motion of the disc was restored; and the same effects were repeatedly obtained. In this experiment both the magnet and the disc were enclosed by glass shades, andsupported on a firm base

The same effects were produced by a mass of silver and zinc: but when their thickness was considerably diminished by removing the central plates, the motion of the disc was not impeded. A very great thickness of *lead* was necessary to stop the disc, in consequence, as Mr. Harris supposes, of its magnetic energy being so much less than that of copper.

With regard to the influence of *heat* on magnetism, Mr. Christie, from a number of experiments made with a torsion balance, the needle being suspended by a brass wire one-four-hundred and fiftieth of an inch in diameter, ascertained the following facts:—

1. Beginning with —3° Fahr. up to 127°, the intensity of magnets decreased as their temperature increased.

2. With a certain increment of temperature the decrement of intensity is not constant at all temperatures, but increases as the temperature increases.

3. From a temperature of about 80°, the intensity decreases very rapidly, as the temperature increases; so that, if up to this temperature, the differences of the decrements are nearly constant; the differences of the decrements also increase.

4. Beyond the temperature of 100°, a portion of the power of the magnet is permanently destroyed.

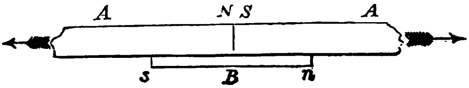
5. On a change of temperature, the most considerable portion of the effect on the intensity of the magnet is produced instantaneously, showing that the magnetic power resides on, or very near the surface.

6. The effects produced on soft iron by changes of temperature, are directly the reverse of those produced on a magnet; an increase of the temperature causing an increase in the magnetic power of the iron. This *was observed* between the temperatures of 50° and 100°

Fahr. Mr. Christie regards this, as a strong argument against the hypothesis, that the action of iron upon the needle arises from the polarity which it receives from the earth.

Methods of making artificial magnets.—Simple induction, by juxta-position with one or more powerful magnets, may suffice for the impregnation of very small bars, and in the infancy of the science, this was the only method employed. For this purpose the bar to be magnetised was simply placed between the opposite poles of two strong magnetic bars of nearly equal power; but as the principles of magnetic induction came to be better understood, these simple methods were discontinued, and a great variety of ingenious and highly effective processes invented. The first of these was that of Mr. Knight. This method, which was kept a secret during his life-time, but which was made public after his death by Mr. Wilson, consisted in placing the bar to be magnetised, after having tempered it at a cherry-red heat, under the opposite poles N S, *Fig.* 68, of two equal magnets. These magnets were then separated in opposite directions, SA′, NA, so that the south pole of the one, passes over the north *polar* half B*n*, of the bar B, and the north pole N of the other half, over the south polar half B*s*, of B: this operation is repeated several times till the magnetism of the bar B is fully developed.

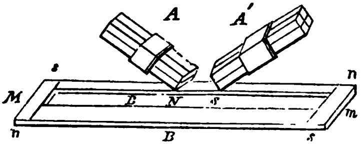
Fig. 68.



In this process, the north pole N, while it attracts to the half B*n*, all the south polar magnetism in B*s*, repels at the same time into B*s* all the north polar magnetism of B*n*. The same is true *mutatis mutandis* with the south pole S. When the bars AA′ are large and powerful, it has been found that this process is capable of communicating to small bars all the magnetism of which they are susceptible.

Soon after the publication of Dr. Knight's method, small bars thus magnetised, were distributed all over Europe, and were eagerly sought after by the cultivators of natural philosophy. When the process however was applied to bars of large size, it was found to be defective; philosophers, therefore, renewed their efforts to devise methods of greater and more universal efficacy. The next improvement was made by M. Duhamel, of the Academy of Sciences, in conjunction with M. Antheaume. It is represented in *Fig.* 69.

Fig. 69.

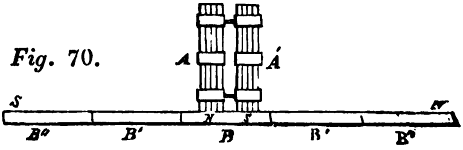


The bars BB to be magnetised, are placed parallel to each other, and have their extremities united by two pieces M*m* of soft iron, at right angles to the bars; two strong magnets, or two bundles of small bar magnets A′A, having their similar poles together, are placed as in the figure, at an angle of about 90°, or inclined 45° to the bar B, and then separated from each other, as in Dr. Knight's method; the same operation is repeated on the other bar B′, and continued alternately on both, till the magnetism is supposed to be completely developed in both bars. When AA′ are placed on the second bar B, the disposition of the poles must be reversed, the pole that was formerly to the right hand, being now turned to the left. The two bars BB′ are then turned, so that the undermost faces are uppermost, and the same process carried on as before.

The peculiarity of Duhamel's process, consists in the employment of the pieces of iron M *m*, and in the use of bundles of small bars, which are more efficacious than two single ones of the same size. In proportion also, as the steel bars acquire magnetism, the connecting pieces participate in the acquisition of a similar power, and serve to retain it in the bars themselves; just as the electricity which is imparted to the inner coating of a Leyden jar, is retained by the reciprocal influence of the induced, and contrary electricity of the outer coating. The magnetism of the bars is retained by a similar influence, and greater facility is thus afforded to increase its amount, by the subsequent additions it is receiving from the action of the magnets, as they pass along the surface.

About the same time that Duhamel was occupied with this subject, Mr. Michell of Cambridge, and Mr. Canton, were separately engaged in the same enquiry. Mr. Michell published his method in 1750, to which he gave the name of *method by double touch.* Having joined together at the distance of a quarter of an inch, two bundles of strongly magnetised bars A A′, *Fig.* 70, their opposite poles N S being together, he placed five

Fig. 70.



or more equal steel bars, B B′ B′ B″ B″ in the same straight line, and resting the extremity of the bundle of magnets A A′ upon the middle of the central bar B, he moved them *backwards and forwards* throughout the whole length of the line of bars, repeating the operation on each side of the bars, till the greatest possible effect was produced. By this method, Mr. Michell found that the middle steel bars B B′ B′ acquired a very high degree of magnetic virtue, and greater than the outer bars B″ B″; but by placing these last bars in the middle of the series, and repeating the operation, they acquired the same power as the rest. Mr. Michell states that two magnets will, by his process of double touch, communicate as strong a magnetic virtue to a steel-bar, as a single magnet of five times the strength, when used in the process of single touch. The bars A A′ act with the sum of their powers in developing magnetism in all parts of the line of the bars between them, and with the difference of their powers in all parts of the line beyond them. The external bars act the same part in this process, as the two pieces of soft iron in the method of Duhamel.

In the year 1831, Mr. Canton published his process, which he regarded as superior to the preceding ones. He placed the bars as in Duhamel's method, joined by pieces of soft iron. He then applied Michell's method of double touch, and afterwards he separated the two bundles of magnets A A, and having inclined them to each other as in Duhamel's method, he made them rub upon the bar from the middle to its extremities. The peculiarity of Canton's method is the union of these two processes; but Coulomb and others are of opinion that *the latter* part of the process is the only effectual one.

In order to make artificial magnets, without the aid either of natural loadstones or artificial magnets, Mr. Canton gives the following detailed process:—

He takes six bars of soft, and six of hard steel, the former being smaller than the latter. The bars of *soft* steel should be three inches long, one-fourth of an inch broad, and one-twentieth thick; and two pieces of iron must be provided, each having half the length of one of the bars and the same breadth and thickness. The bars of *hard* steel should be each five and a half inches long, half an inch broad, and three-twentieths of an inch thick, with two pieces of iron of half the length, and of the same breadth and thickness.

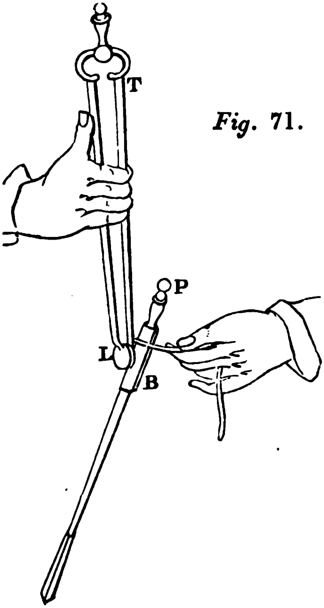
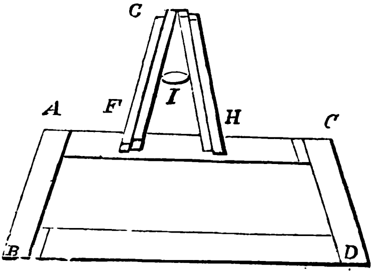


Fig. 71.

All the bars being marked with a line quite round them at one end, take an iron poker and tongs, or two bars of iron, the larger and the older the better, and fixing the poker upright as in *Fig.* 71, hold to it with the left hand near the top P by a silk thread, one of the soft bars B, having its marked end downwards; then grasping the tongs T, with the right hand a little below their middle, and keeping them nearly in a vertical line, let the bar B be rubbed with the lower end L of the tongs, from the marked end of the bar to its upper end, about ten times on each side of it. By this means the bar B will receive as much magnetism as will enable it to lift a small key at the marked end; and this end of the bar being suspended by its middle, or made to rest on a joint, will turn to the *north*, and is called its *north* pole, the unmarked end being the *south* pole.

When four of the soft steel bars are thus rendered magnetic, the other two A C, B D, *Fig.* 72, must be laid parallel to each other, at the distance of about one fourth of an inch, having their dissimilar poles united by the smallest pieces of iron A B, C D. Two of the magnetised bars are then to be placed together as at G, with their similar poles united, and when separated by a piece of wood at I, they are slid four or five times backwards and forwards along the whole length of the bar A C, so that the marked end F of G is nearest the unmarked end of A C, and *vice versa*.

Fig. 72.



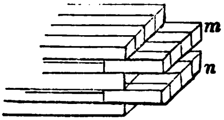
This operation is carefully repeated on B D, and on the other sides of both A C and B D. When this is done, the bars A C and D are to be taken up and substituted for the two outer bars of the bundles G K;— these last being laid down in the place of the former, and magnetised in a similar manner. This operation must be repeated, till each pair of the soft bars has been magnetised three or four times.

When the six soft bars are thus magnetised, they must be formed into two bundles of three each, with their similar poles together, and must be used to magnetise two of the *hard* bars in the manner already described; and when they are magnetised, other two of the hard bars must be touched in a similar manner. The soft bars are now to be laid aside, and the remaining two *hard* bars magnetised by the *four* hard bars already rendered magnetic; and when this is done, the operation should be repeated by interchanging the hard bars, till they are impregnated with the greatest degree of permanent magnetism which this method is capable of communicating to them.

In performing the above operations, which may be completed in about half an hour, the bars A C, B D, and the pieces A B, C D, should be placed in grooves or fixed between pins of wood or brass, to keep them steady during the successive frictions which are applied to them. According to Canton, each of the six artificial magnets thus made, will lift about twenty-eight ounces troy. They should be kept in a wooden box, and placed so that no two poles of the same name may be together,—the pieces of iron being placed beside them.

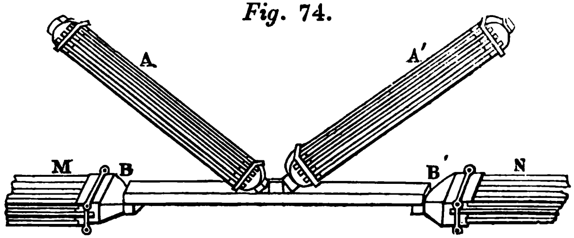
The following is an account of Coulomb's method of making artificial magnets, which consists of the most efficacious parts of the preceding processes, improved and extended by long experience. The apparatus which he uses consists of *fixed* and *moving* bundles of magnets. Each of the fixed bundles consists of *ten* bars of steel, tempered at a cherry-red heat, their length being about twenty-one inches, their breadth six-tenths of an inch, and their thickness one-fifth of an inch. Having rendered them as strongly magnetic as possible, with a natural or artificial magnet, he joined them with their similar poles together, and formed them into two beds of four bars each, these beds being separated by small rectangular parallelopipeds M N, of soft iron, projecting beyond their extremities, as shown in *Fig.* 73.

Fig. 73.



The *moving* bundles consist of four bars tempered at a cherry-red heat, each being about sixteen inches long, six-tenths of an inch wide, and two-tenths of an inch thick. When these bars were magnetised in the same way as the other bars, he united two of them by their width, and two of them by their thickness, so that each bundle was one inch and two-tenths wide, and four-tenths thick. The bars being separated as before by pieces of soft iron, Coulomb found that all kinds of steel, provided it were not of a bad quality, were capable of receiving the same degree of magnetism. In order to magnetise a bar, he placed the large fixed *bundles* M N, *Fig.* 74, in the same straight line, and at a distance a little less than the length of the bar to be magnetised; and this bar B B, was placed as in the figure so as to rest on the projecting pieces of iron, so that the contact took place only over a length of

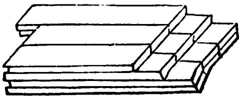
Fig. 74.



one-fifth of an inch: the two moving bundles A A′, having their dissimilar poles separated by a small piece of wood or copper, about one-fifth of an inch wide between them; and each being inclined at an angle of 20° or 30° to the bar B B′. The united poles of the moving bundles are then moved successively from the centre to each extremity of the bar B B′, so that the number of frictions upon each half of the bar may be equal. When the last friction has been given, the united poles are brought to the middle point of the bar B B′, and then withdrawn perpendicularly. The same operation is then repeated on the other side of the bar B B′. If we wish to employ the method of Duhamel, we do not require the piece of wood or copper, but have only to separate the bars when the united poles are in the middle of the bar B B′, making each pole pass to the extremity of it.

If the pieces composing the moveable magnets have not received their full power they will, notwithstanding, communicate to the bars subjected to their action, a *greater* degree of magnetism than they possess themselves. We may therefore now increase *their* power, by repeating the process on them with the bars which they have themselves impregnated: by so doing three or four times, we shall succeed in effecting their complete saturation. If the bars to be magnetised be very large, Coulomb recommends an increase of the number of the moveable magnets, each of the bars projecting beyond the last as shown in *Fig.* 75. Thus the pole of each, which Coulomb supposes generally to reside at the very extremity of the bar, will come immediately in contact with the bar to be mag-

Fig. 75.

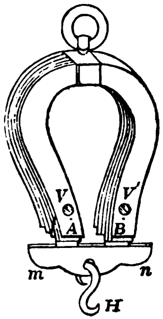


netised, when the compound magnet is applied to it with the proper inclination, and the whole will powerfully conspire to produce the same effect.

Horse-shoe magnets. The form of a horse-shoe is generally given to magnetic bars when both poles are wanted to act together, which frequently happens in various experiments; such as for lifting weights by the force of magnetic attraction, and for magnetising steel bars by the process of double touch, for which they are exceedingly convenient; fulfilling in this operation all the purposes of compound magnets.

The following is the method of making a powerful magnetic battery of the horse-shoe form, recommended by Professor Barlow:—"Take bars of steel, twelve inches long, and bend them into a horse-shoe shape, their length being six inches, their breadth one inch at the curved part, and three-fourths of an inch at their extremities, and their thickness one-fourth of an inch. Let them be filed nicely, so as to correspond, and lie flatly upon each other. Then drill three holes in each as shown in *Fig.* 76, and by means of screws v v, passing through these holes, let *nine* horse-shoe bars be bound together. When the heads and ends of the screws are constructed, so as to leave the outer surfaces smooth, the mass of bars must be filed as if they were one piece, and the surface made flat and smooth. When the bars are separated, let them be carefully hardened so as not to warp; and when they are cleaned and rendered bright, but not polished, magnetise them separately in the following manner:—when the two

Fig. 76.



extremities of the bar are connected by a piece of soft iron M, the magnetism may be developed in the two halves by Duhamel's method as in *Fig.*77; or, following Epinus, a strong magnet may be applied to each pole, and connect their extremities, either with a piece of soft iron, or another magnet, or two horse-shoe magnets may be applied to each other, as in *Fig.* 78, uniting the poles which are to be of contrary names. When the magnets are prepared in any of these ways, they are then to be magnetised with another horse-shoe magnet, A B; by placing its north pole next to what is to be the south pole of one of the horse-shoe bars, and then carrying the moveable magnet round and round, but always in the same direction. In this way, a very high degree of magnetic virtue may be communicated to each of the *nine* bars. When this is done, they are to be re-united by the three screws; and their poles or extremities connected by a piece of soft iron, or lifter as

Fig. 77.

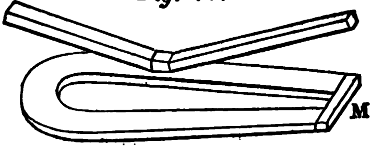
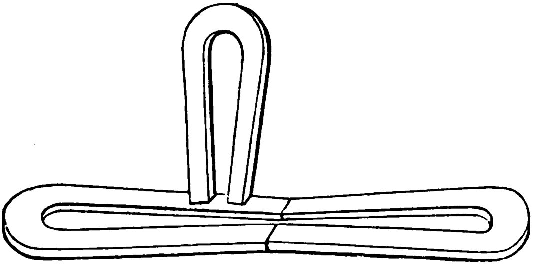


Fig. 78.



in *Fig.* 76; having in its middle a hook H, for suspending any weight. As the lifting power depends on tho accurate contact of the poles of the magnet with the lifter, the extremities should, after hardening, be properly rubbed down with putty on a flat suface.

A magnet of this size and form, was found by Professor Barlow, to suspend *forty pounds*: but he afterwards found, that a greater proportional power could be obtained by using bars that were long in comparison with their breadth.

The following is another simple and efficacious method of making artificial magnets, which has been successfully practiced by Mr. Barlow. Having occasion for thirty-six magnets, twelve inches long, one and a fourth broad, and seven sixteenths of an inch thick, he placed thirty-six bars of steel of these dimensions on a table so as to form a square, having *nine* bars on each side, the marked or north pole of each bar being in contact with the unmarked or south pole. At the angular points of the square, the under edges of the bars were brought into contact, and the external opening thus left was filled up by a piece of iron one inch and a quarter square, and seven-sixteenths of an inch thick. The horse-shoe magnet described in the preceding section, was set upon one of the bars, so that its *north* pole was towards the unmarked end of the bar, and was then carried or rubbed along the four sides of the bars, and the operation was continued till the compound magnet had gone twelve times round the square. Without removing the magnet, each bar was turned one by one, so as to bring their lower sides uppermost, and the horse-shoe magnet was made to rub along the four sides of the square other twelve times.

The bars were then highly magnetised, and the whole process did not occupy more than half an hour.

This last process is the simplest, quickest and most efficacious of all the methods that have been described; so that when a person is in possession of one good horse-shoe magnet, consisting of three or four bars joined together, he may afterwards make any number at the same time: indeed the more the better. In removing the bars from each other after they have undergone the operation, it is advisable to place small pieces of soft iron on the poles of each, before they are separated, for it is a fact well known to experimentalists, that a very considerable portion of the power of a bar is lost at the moment of its separation from others that have been impregnated with it; nor is it possible, by any means to secure the whole of the magnetism that has been given to it. By following the plan recommended above however, it will be found that a much larger portion is retained. The whole of the bars become, in fact, as one single magnet, and the act of separation is of course analagous to that of fracture.

Magnets should, when laid aside, be placed as nearly as possible in the position which they would assume in consequence of the action of terrestrial magnetism; if this be neglected, in process of time they will become gradually weaker; and this deterioration is most accelerated when its poles have a position the *reverse* of the natural one. Under these circumstances indeed, unless the magnet be made of the hardest steel, it will eventually lose the whole of its magnetic power. Two magnets may also very much weaken each other, if they be kept, even for a short time, with their *similar* poles fronting each other. This will readily be understood from what has been said with regard to magnetic induction. The polarity of the weaker magnet is rapidly impaired, and sometimes actually reversed. All rough and violent treatment of a magnet should also be carefully avoided :—every concussion or vibration amongst its particles tends to weaken its power.

Horse-shoe magnets should have a short bar of soft iron, adapted to connect the two poles; and should never be laid by, without such a piece of iron adhering to them. Bar magnets should be kept in pairs, with their poles turned in contrary directions, and the dissimilar poles on each side connected by a bar of soft iron, so that the whole may form a parallelogram. They should fit into a box when thus arranged, so as to guard against accidental concussion, and to preserve them from the dampness of the atmosphere. They should be polished not with a view of increasing their magnetism, but because they are then less liable to contract rust. Both single magnets and needles have their power not only preserved but increased, by keeping them surrounded with a mass of dry filings of soft iron, each partical of which will re-act, by its induced magnetism upon the point of the magnet to which it adheres, and maintain in that point its primitive magnetic state.

In the "Compte Rendu" for January 2nd, 1838, there is an important notice of a communication received from M. De la Rive, relative to the magnetising of needles by the *nerves* :—the following is an extract. "Dr. Prevost, of Geneva has succeeded in magnetising very delicate soft iron needles, by placing them near the nerves, and perpendicular to the direction which he supposed the electric current took. The magnetising took place at the moment when, on irritating the spinal marrow, a muscular contraction was effected in the animal."

There is another method of forming very powerful magnets, which I shall only briefly notice here, as it will form a part of a future lecture, namely, by induced electrical currents: soft iron is employed, and the magnetism is only temporary. The process consists in winding spirally round a horse-shoe bar of iron, a copper wire covered with silk thread. A galvanic current is then made to pass through the wire, and at the moment the contact between the wires and the single voltaic circle is completed, the soft iron becomes powerfully magnetic. Professor Henry mentions a horse-shoe bar of soft iron weighing twenty one pounds, which, when magnetised by this process, lifted more than thirty-five times its own weight; whereas the largest natural magnet known, and in the possession of Mr. Peale of Philadelphia, lifts three hundred and ten pounds, or about six times its own weight.

LECTURE VI.

ON MAGNETISM.

THE tendency of the magnetised needle or bar to turn *nearly* to the north and south when left at liberty to move freely on a pivot, or otherwise suspended so as to allow of freedom of motion, in a horizontal plane, is derived from a force naturally supposed to reside in the earth. It is found that in this country, as well as throughout Europe, the north pole of the compass deviates a certain number of degrees (about 25°,) to the westward of the true north: this deviation is called the magnetic *declination* or *variation*. The vertical plane which passes through the direction of the horizontal needle at any particular place, is called the *magnetic meridian* of the place, in contra-distinction to the *geographical* or *true meridian*, which is a vertical plane passing through the poles of the earth. On this property of the needle is founded that instrument which is of such indispensable utility to the sailor, the mariner's compass.

The force of terrestrial magnetism is not only exerted on bodies possessed of magnetic power, but also on unmagnetised bodies: a piece of iron may be rendered permanently magnetic by it. It is found that when a bar of soft iron is held in the direction of the magnetic meridian, and inclined to the horizon, it is converted into a temporary magnet possessed of a north and south pole, and if it be kept for a very long time in that position, it acquires permanent magnetism. Old kitchen pokers that have been in use for a number of years, and which, when laid aside have frequently the exact position required, are often found to be permanently magnetic; the lower end exhibiting all the properties of a north pole, repelling the north, and attracting the south pole of the needle, while the upper end is a true, though much weaker south pole, repelling the south and attracting the north pole of the needle.

But not only does the balanced magnetised needle point to the north and south, in consequence of terrestrial magnetism, it is found to be endued with another property also. If we take a needle and balance it on a pivot with the greatest accuracy, it will of course lie horizontally on its axis; but if we magnetise it, it will no longer remain in a horizontal position, but will be found to take an inclined position, the north end appearing to preponderate: this arises from the effects of the *dip*, which in this country is about 70°.

Thus the magnetic force may, by the ordinary dynamic mode of resolution of forces, be resolved into two forces, the one acting vertically, and the other horizontally. The latter of these forces is the only one with the action of which gravitation does not interfere; and accordingly, the mariners' compass indicates by its motions the effects of this part of the terrestrial magnetic force, and this only. In order to ascertain the vertical force we must proceed in a different manner. The needle must be furnished with an axis at right angles to its length, and adjusted very carefully, so that it may pass as exactly as possible through its centre of gravity. This of course can only be done when the needle is wholly free from magnetism, and secured from all magnetic influence which the earth might exert upon it. The axis should be supported horizontally, in such a manner as to allow the needle complete freedom of motion in a vertical plane. The needle being balanced will have no tendency to incline to one side rather than to another, and will remain at rest in any position in which it may happen to be left, as long as no extraneous force is applied to it, and when it is magnetised it will be in a condition to illustrate the property of the dip. I shall consider these two important classes of phenomena in reference to terrestrial magnetism in their order. 1st, The variation—and, 2dly, The dip of the needle. Measures of the variation of the needle have been taken by navigators and travellers in all parts of the globe. In some places the magnetic and terrestrial meridian exactly correspond; in these situations the needle points to the true north and south; but in most parts of the earth's surface, its direction deviates, sometimes to the east and sometimes to the west. We are indebted to Professor Hansteen for the most satisfactory collection of observations on the variation of the needle, and for the most philosophical generalization of them. He has published a variation chart for 1787, in which it is shown how irregular are the causes on which terrestrial magnetism depends, by *the total* want of symmetry, and the irregularities and inflexions of the magnetic curves. He makes the *western line of no variation*, or that which passes through all the places on the globe where the needle points to the true north, to begin in latitude 60° to the west of Hudson's Bay, proceeding in a south east direction through the North American Lake, passing the Antilles and Cape St. Roque, till it reaches the South Atlantic Ocean, where it cuts the meridian of Greenwich at about 65° of south latitude. This line of no variation, is extremely regular, being almost straight till it bends round the eastern part of South America, a little south of the equator. On the other hand, his chart shews that the *eastern line of no variation*, is extremely irregular, being full of loops and inflexions of the most extraordinary kind, indicating the action of local magnetic forces. It begins in latitude 60° south, below New Holland, crosses that immense island through its centre, extends through the Indian Archipelago with a double sinuosity, so as to cross the equator three times; first passing north of it to the east of Borneo, then returning to it and passing south through Sumatra and Borneo, and then crossing it again beneath Ceylon, from which it passes to the east through the Yellow Sea. It then stretches along the coast of China, making a semicircular sweep to the west till it reaches the latitude of 70°, where it descends again to the south, and returns northward with a great semicircular bend, which terminates in the White Sea.

These lines of no variation are accompanied through all their windings by other lines, where the variation is 5°, 10°, 15°, &c.; these lines becoming more irregular as they recede from those of no variation.

In 1833, Professor Barlow constructed a new variation chart, in which he has inserted the magnetic observations of Commander Ross; and he remarks, that the very spot where this officer found the needle perpendicular, "that is, the pole itself, is precisely that point in my globe and chart in which, by supposing all the lines to meet, the several curves would best preserve their unity of character, both separately and conjointly as a system."

Hansteen is of opinion, that there are *four points of convergency* in each hemisphere; and that these points are to be considered as the *four magnetic poles of the globe*. He concludes that they have a regular motion round the globe; the two northern ones from west to east, in an oblique direction; and the two southern ones from east to west, also obliquely. The following are the calculated periods of their revolution.

The strongest *north* pole in	1740 years.
The strongest *south* pole in	4609 years.
The weakest *north* pole in	860 years.
The weakest *south* pole in	1304 years.

Hansteen considers the four poles as originating in *two* magnetic axes, the two strongest being the termination of one axis, and the two weakest of the other; and he conceives that they may have been produced, either along with the earth itself, or at a later epoch. According to the first supposition, it is not easy to account for their change of position: but according to the last they must have originated either from the earth alone, or from some external cause. If they originated in the earth, their change of position is still unsusceptible of explanation; and hence Hansteen conceives that *they* have their origin from the action of the sun, heating and illuminating the earth, and producing a magnetic tension as it produces electrical phenomena.

The following table exhibits the progressive changes in the variation of the needle, which have taken place in London.

Years.	Observers.	Variations.
1576	Norman	11°15′ Easterly.
1580	Burroughs	11°17′ Maximum.
1622	Gunter	6°12′
1634	Gellibrand	4°5′
1657 1662	....	0 0 No variation
1666	....	0 34′ Westerly.
1670	....	2° 6′
1672	....	2° 30′
1700	....	9° 40′ Westerly.
1720	....	13° 0′
1740	....	16° 10′
1760	....	19° 30′
1774	....	22° 20′
1778	Phil. Trans.	22° 11′
1790	....	23° 39′
1800	....	24° 36′
1806	Phil. Trans.	24° 8′
1813	Col. Beaufoy	24° 20′ 17″
1815	Ditto	24° 27′ 18″ Maximum
1816	....	24° 17′ 9″
1820	....	24° 11′ 7″
1823	....	24° 9′ 40″
1831	....	24° 0′ 0″

These progressive changes are referred by Hansteen to the motion of four magnetic poles.

An *annual* change in the variation of the needle, depending on the position of the sun, in reference to the equinoctial and solstitial points has been observed by M. Cassini.

Between the months of January and April, the magnetic needle recedes from the north pole of the globe, so that its western declination increases.

From April to the beginning of July, that is, from the vernal equinox to the summer solstice, the declination diminishes, or the needle approaches the north pole of the globe.

From the summer solstice to the vernal equinox, the needle receding from the north pole, returns to the west, so that in October it has nearly the same position as in May, and between October and March, the western motion is smaller than in the three preceding months. Hence it follows that during the three months between the vernal equinox and the summer solstice, the needle retrogrades towards the east; and during the following *nine* months its general motion is towards the west.

There is also a daily change in the variation of the needle; this was first observed in 1724, by Mr. Graham, and has been confirmed with the most accurate instruments in almost every part of the world. When it was first discovered, the needle was supposed to have only two changes in its movements during the day. About seven, A. M., its north end began to deviate to the west; and about two, P. M., it reached its maximum westerly deviation; it then returned eastward to its first position, and remained stationary till it again resumed its westerly course in the following morning. It was afterwards found that the diurnal motion commences much earlier than seven, A. M., but its motion is to the east. At half past seven, A. M., it reaches its greatest easterly deviation, and then begins its movement to the west, till two, P. M. It then returns to the eastward till evening, when it has again a slight westerly motion; and in the course of the night, or early in the morning, it reaches the point from which it set out twenty-four hours before.

At Paris, the needle is nearly stationary during the night. At sun-rise its north extremity moves westward, as if it were avoiding the solar influence. Towards noon, or more generally from noon to three o'clock, it attains its maximum westerly deviation, and and then it returns eastward till nine, ten, or eleven o'clock in the evening; and then, having reached its original position, it remains stationary during the night. The amount of this daily variation, is, for April, May, June, July, August, and September, from 13′ to 15′; and for the other six months of the year, from 8′ to 10′; on some days it rises to 25′, and on others, it does not exceed 5′ or 6′.

The dipping needle also undergoes daily variations, but their amplitude is of less amount; and there is no doubt that a needle capable of moving in any given azimuth, will experience daily changes; and that a needle moveable in every direction round its centre of gravity, would describe every day a cone, whose base would be an ellipse, or some other curve, more or less elongated, in different parts of the earth.

The sun is now universally allowed to be the cause of the diurnal variations of the needle. Canton ascribed them to the action of solar heat, having ascertained that heat tends to diminish the attractive powers of a magnet, and assuming that the direction of the needle, was due to the resultant of all the magnetic forces of the terrestrial sphere. When the sun was to the eastward of the needle, the forces lying to the eastward suffered a diminution of power, in consequence of which, the westerly force prevailed, and the north end deviated to the west. When the sun on the other hand was to the westward of the needle, the power on that side diminished, and the needle returned again to the eastward. Canton, did not, however, give any explanation of the morning easterly variation of the needle.

M. M. Morlet and Hansteen have determined the true form of the magnetic equator (an irregular line crossing the equator at *four* points) with great care; they have traced it over the whole globe, and found that its motion is from east to west, in so far as can be determined by direct observations on the position of its nodes. They both place the magnetic equator wholly to the south of the terrestrial equator, between Africa and America; its greatest southern latitude being at 25°. One node is in Africa, in about 22° of east longitude, or in 18° according to Morlet. In setting out towards the east from this node, which is nearly in the centre of that part of the African continent, the magnetic equator advances rapidly to the north of the terrestrial equator, quits Africa a little to the south of Cape Guardafui, and in the Arabian Sea it attains its most northerly latitude of about 12°, in 62° of east longitude; between this meridian, and 174° east, the magnetic equator is constantly to the north of the equinoctial line. It cuts the Indian peninsula a little to the north of Cape Cormorim, traverses the gulf of Bengal, making a slight advance to the equinoctial, from which it is only 8° distant at the entry of the Gulf of Siam. It then re-ascends a little to the north, *almost* touches the north point of Borneo, traverses the

Isle of Paragua, the strait which separates the most southern of the Philipines, from the Isle of Mindanao, and under the meridian of Naigiou, it again reaches the north latitude of 9°. From this point it traverses the Archipelago of the Caroline Islands, and descends rapidly to the equinoctial line, which it cuts according to Morlet in 174°, and according to Hansteen in 187° east longitude. There is much less uncertainty respecting the position of a second node, also situated in the Pacific Ocean. Its west longitude ought to be about 120°; but while M. Morlet's inquiries lead him to conclude that the magnetic equator merely touches the equinoctial at that point, and then bends again to the south—M. Hansteen makes it cross the line into the northern hemisphere, and continue there through an extent of 15° of longitude, and then return southward, and cross the equinoctial again in about 108° of west longitude, or 23° from the west coast of America. This discrepancy between the results of Morlet and Hansteen, is, after all, very trivial; for, in the case just mentioned, the magnetic equator does not go more than 1½° to the north of the equinoctial; and in general the magnetic equator of Morlet differs in no part so much as 2° in latitude from that of Hansteen.

The observations of Captain Duperrey made on board the Coquille, in the years 1822-25, have contributed considerably to our stock of knowledge on the subject of terrestrial magnetism, and particularly on the form and motion of the magnetic equator. This vessel crossed the magnetic meridian six times, and M. Duperrey was enabled to determine directly two of its points, situated in the Atlantic Ocean. On the chart of Morlet, and in that of Hansteen, the latitudes of those parts, which correspond to the same longitudes, are greater by 1°43′ and 1°50′; and hence M. Arago has concluded that the magnetic equator has approached the terrestrial equator by the same quantities. In the South sea, near the coast of America, Duperrey has determined two points of the magnetic equator. On the charts of Morlet and Hansteen, the latitudes of these points is about a degree smaller, but the difference is in a direction contrary to that which was found in the Atlantic Ocean; from which it follows, that near the coast of Peru, the magnetic equator has removed from the equinoctial line.

In a chart of the equatorial regions, which M. Duperrey has drawn up and published in the Annales de Chimie, for 1830, these results are laid down: "That the magnetic equator will meet the equinoctial line only in two points, which are diametrically opposite, the one situated in the Atlantic Ocean, and the other in the great ocean, nearly in the plane of the meridian of Paris. When this equator meets only some scattered islands, it recedes only a little from the equinoctial line; when the islands are more numerous, it recedes farther; and it reaches its maximum deviation in both hemispheres, only in the two great continents which it traverses. He found also, that between the northern and southern halves of the magnetic equator, there is a symmetry very remarkable, and much more perfect than had previously been believed.

"The dip of the needle increases on each side of the magnetic equator; and Hansteen has projected lines of equal dip in his chart. These lines are nearly parallel to the magnetic equator, till we reach 60° of *north* latitude, and they then begin to bend round the

American magnetic pole, which Commander Ross found to be situated in north latitude, 70° 5′ 17″, and west longitude, 96° 45′ 48″, the needle having at this point, in Boothia Felix, lost wholly its directive power, and the dip being 89° 59′, within *one minute* of 90° or vertical. Had we inferred the position of the needle from the form of the magnetic equator, we should have placed it in 25° of west longitude, viz: the meridian in which the magnetic equator advances farthest to the south, or about 13½° and 76½° of north latitude, or 90°—13½°. This, however, as all arctic observations prove, is not the case; and we are led by the phenomena of the dip, as well as by those of the variation in different parts of the globe, to conclude that every place has its own magnetic axis, with its own pole, and its own equator, as stated by Mr. Barlow."

The dip of the needle, like the variation, undergoes a continual change, increasing in some parts of the world, and diminishing in others. The following tables show the changes of the dip at London, since 1720; and at Paris, from 1671 to 1829:—

AT LONDON.

Year.	Observed.		Computed.
1720	74°42′	Graham	76°27′
1773	72 19	Heberden	73 40
1780	72 8	Gilpin	73 18
1790	71 53	ditto	72 39
1800	70 35	ditto	71 58
1810			71 15
1818	70 34	Kater	70 34
1821	70 3	Sabine	...
1828	69 47	ditto	69 43
1830	69 38	ditto	....
1833			69 21

AT PARIS.

Year.	Dip.	Year.	Dip.
1671	75° 0′	1818	68°35′
1754	72 15	1819	68 25
1776	72 25	1820	68 20
1780	71 48	1821	68 14
1791	70 52	1822	68 11
1798	69 51	1823	68 8
1806	69 12	1824	68 7
1810	68 50	1825	68 0
1814	68 36	1826	68
1816	68 40	1829	67 41 Arago
1817	68 38		

M. Humboldt has shown that the progressive variation in the dip of the needle, is the necessary consequence of a change in the magnetic latitude, arising from the motion of the nodes of the magnetic equator, modified by the form of this curve. And Morlet has applied the same principle, to account for the variations of the dip in different parts of the globe. From a series of observations made with a dipping needle by Dollond, Hansteen has found that the dip during the summer, was about fifteen minutes greater than during the winter, and about four or five minutes greater in the forenoon than in the afternoon.

It has become a most important practical problem, connected with the physical condition of the globe, to determine the intensity of its magnetism at different points on its surface, and the changes which it undergoes at different seasons of the year, and at different times of the day.

Mr. Graham first suggested a method of determining this, by the number of oscillations of the magnetic needle. And this plan has been since much improved by Coulomb, Humboldt, and others.

If a needle, whose axis of suspension passes through its centre of gravity, and which has its north and south polar magnetism equal, and similarly distributed, be made to vibrate, by turning it from its position, and allowing it to recover that position by a series of oscillations, it is evident that the magnetism of the earth will act with equal force on each half, and that the needle will be drawn into the magnetic meridian by the combined action of both forces. The greater the magnetic force, the more quickly will the needle oscillate, and recover its primitive position. The needle is in short, in the same circumstances as a pendulum, oscillating by the action of gravity; and as in this case, the forces are as the squares of the number of oscillations made in the same time.

Suppose the dipping needle is made to oscillate in the plane of the magnetic meridian, round the line of the dip, and that when an experiment is made at the equator, the number of oscillations in a second is 24, while in another place it is 25; then the intensity of the magnetic force at these places, is as 25^2 to 24^2, or as 625 to 576, or as 1·085 to 1·000. By carrying the same needle to different parts of the earth, the magnetic intensity at these places will be found from the number of its oscillations.

In the application of this method, there are various practical difficulties, particularly the necessity of the needle resting on knobs, edges of steel, or agate, during its oscillations; these difficulties are avoided by suspending it by a fibre of silk, and allowing it to oscillate horizontally. This method is therefore the one adopted, though a little calculation is necessary to obtain the intensity of terrestrial magnetism, from the number of oscillations that are performed.

Hansteen has drawn up a table, which is too long for insertion here, exhibiting the magnetic intensity in almost every part of the world, from observations made principally by himself and his friends. He has projected on a map of the globe, the lines passing through all the places in which the intensity has the same value. These lines he calls *isodynamic lines*, or those of equal force, and they are, generally speaking, nearly parallel to each other, and to the lines of equal dip.

The same indefatigable philosopher, not satisfied with the many valuable observations which were made during the various arctic expeditions which were sent out by the British government, and being exceedingly anxious to establish, by direct observations of his own, the existence of the secondary magnetic pole, which he believed existed in Siberia, undertook a journey at the expence of the Norwegian Storthing and with every encouragement and assistance from the Russian Government. The results of his expedition were highly satisfactory; and in conseqence the Russian Academy of Sciences have been induced to take a new interest in the subject of terrestrial magnetism, which exhibits such important features throughout the Russian empire; and the Russian government has established regular observatories in various parts of its vast dominions for making magnetic experiments. The Russian empire is actually traversed by *two* lines of no variation, and it is proposed to determine with great precision, *every ten* years, the exact position of these two lines.

Near the first of them, which traverses European Russia, Petersburgh, Moscow and Kasan are situated; and near the second, which passes through Siberia, is situated Kiachta and Nizni Oudinsk. Observations are yet wanting to determine in what manner the intensity varies with the height. Humboldt is of opinion that it decreases, confirming the deductions of Kupffer.

By combining all the observations of intensity from 179° to 183°, M. Hansteen has drawn the conclusion, *that the total magnetic intensity is smaller in the southern than in the northern hemisphere.* M. Duperrey has confirmed this result.

The magnetic intensity, like the variation and dip of the needle, undergoes monthly and diurnal changes. Hansteen found by means of the vibrations of a needle delicately suspended, that the *minimum* of daily change of intensity is between ten and eleven in the forenoon, and the *maximum* between four and seven in the afternoon in May, and about seven in June. The intensity is a maximum in December, and a minimum in June. The greatest monthly change in the intensity is a maximum in the months of December and June, about the time when the earth is in its perihelion and aphelion. It is minimum near the equinoxes, or when the earth is at its mean distance from the sun. The greatest daily change is least in the winter and greatest in the summer. The greatest difference of the annual intensity is 0·0359. M. Hansteen has likewise found that the magnetic intensity is diminishing in Europe, and that the decrease is greater in the northern and eastern, than in the southern and western parts; an effect which he conceives to be produced by the motion of the Siberian pole towards the east. At port Bowen, Captain Parry observed an augmentation of the magnetic intensity to take place from the morning till the afternoon, and a diminution of it from the afternoon till the morning. These results of M. Hansteen have been confirmed by Mr. Christie, (Philosophical Transactions 1825, p. 49-51,) who has shown that the terrestrial magnetic intensity is a minimum between ten and eleven o'clock in the morning; the time nearly when the sun is in the magnetic meridian; that it increases from this time until between nine and ten o'clock in the evening, after which it decreases, and continues decreasing during the morning, till it reaches its minimum between ten and eleven. These results were deduced from observations made in May, *within doors*, to determine the positions of the points of equilibrium at which a magnetic needle was retained, at different hours during the day, by the joint action of two bar magnets, and by terrestrial magnetism, reduced to their true positions at the standard temperature 60° of the magnet.

Mr. Christie repeated his observations *in the open air* in June, and from these it appears that the minimum intensity happened nearly at the time the sun passed the magnetic meridian, and rather later than in May, which was also the case with the time of the sun's passage over the meridian. The intensity increased till about six o'clock in the afternoon, after which it appears to have decreased during the evening, and to have been decreasing from an early hour in the morning. The following table shews the results of the observations of Mr. Christie, compared with those of M. Hansteen :—

Intensity deduced from Hansteen's observations in 1820.			Intensity deduced from Mr. Christie's observations in 1823.		
TIME.	MAY.	JUNE.	TIME.	MAY.	JUNE.
8h 0′ A.M.	1·00034	1·00010	7h 30′	1·00114	1·00061
10 30	1·00000	1·00000	10 30	1·00000	1·00000
4 0 P.M.	1·00299	1·00251	4 30	1·00175	1·00223
7 0	1·00294	1·00304	7 30	1·00220	1·00339
10 30	1·00191	1·00267	9 30	1·00231	1·00209

The principal difference between these results is, that in Mr. Christie's observations, the intensity seems to diminish more rapidly in the morning, and increase more slowly in the afternoon, than it does in those of Hansteen.

In April, 1836, Baron Alexander Von Humboldt addressed a letter to His Royal Highness the Duke of Sussex, president of the Royal Society of London, to solicit the co-operation of that body towards the advancement of the knowledge of terrestrial magnetism, by the establishment of magnetic stations, and corresponding observations, and soliciting it to extend, in the colonies of Great Britain, the line of simultaneous observations; these stations he proposed to be established, either in the tropical regions on each side of the magnetic equator, or in the high latitudes of the southern hemisphere, and Canada.

This distinguished traveller, has been for many years much occupied with the phenomena of the intensity of the magnetic forces, and the inclination, and declination of the magnetic needle. During the years 1806 and 1807, particularly at the periods of the equinoxes and solstices, he measured the angular alterations of the magnetic meridian, at intervals of an hour, often of half an hour, without interruption, during four, five, and six days, and as many nights, in a large garden at Berlin. The instrument he employed, was a magnetic telescope, *(lunette aimantée)* of Prony, capable of being reversed upon its axis, suspended according to the method of Coulomb, placed in a glass frame, and directed towards a very distant meridian mark, the divisions of which illuminated during the night, indicated even six or seven seconds of *horary* variation. In verifying the habitual regularity of a *nocturnal period*, he was struck with the frequency of the perturbations, especially of oscillations, the amplitude of which, extended beyond all the divisions of the scale, and which occurred repeatedly at the same hours before sun-rise, and the violent and accelerated movements of which, could not be attributed to any accidental mechanical cause. These vagaries of the needle, the almost periodical return of which has recently been confirmed by M. Kupffer, appeared to Humboldt the effect of a re-action of the interior of the earth towards the surface, of *magnetic storms*, which indicate a rapid change of tension. From that time, he says, he has been anxious to establish on the east and west of the meridian of Berlin, apparatus similar to his own, in order to obtain corresponding observations, made at great distances, and at the same hours.

In 1827, Baron Humboldt renewed these observations at Berlin, and endeavoured at the same time to generalize the means of simultaneous observations, the accidental employment of which, had produced such *important* results. One of Gambey's compasses was placed in the *magnetic pavilion*, in which no portion of iron was introduced, which had been erected in the middle of a garden. At his request, the Imperial Academy and the Curator of the University of Cazan, erected *magnetic houses* at St. Petersburgh and at Cazan, and the Imperial Department for Mines having concurred in the same object, *magnetic stations* have been successively established at Moscow, Barnaoul, and at Nertschinsk. The Academy of St. Petersburgh has done still more, and has sent a courageous and clever astronomer, M. George Fuss, the brother of its perpetual secretary, to Pekin, and has procured the erection there of a *magnetic pavilion* in the convent garden of the Monks of the Greek church. Since the return of M. Fuss, M. Kowanko continues the observations of horary declination, corresponding to those of Germany, St. Petersburgh, Cazan, and Nicolajeff in the Crimea, where Admiral Greigh has established one of Gambey's compasses, the care of which is confided to the director of the observatory, Mr. Knorre. A magnetic apparatus has also been established at the depth of thirty-five fathoms, in an adit in the mines of Freiberg, in Saxony, where M. Reich, to whom we are indebted for valuable experiments and observations upon the mean temperature of the earth at different depths, is assiduously engaged in making observations at regulated intervals. Observations of horary declination, made at Marmato, in the province of Antioquia, in South America, in north lat. 5°27′, in a place, where, as at Cazan and Barnaoul, in Asia, the declination is eastern, have been transmitted by M. Boussingault; while on the north western coasts of the new continent, at Sitka, in the Russian settlements, Baron Von Wrangal, also provided with one of Gambey's compasses, has taken part in the simultaneous observations made at the time of the solstices and equinoxes. Magnetic apparatus have also been sent by Baron Humboldt to Havannah and Cuba; and M. Arago has erected a compass, at his own expence, in the interior of Mexico, where the soil is elevated six thousand feet above the level of the sea. Preparations are likewise making for the establishment of a magnetic station in Iceland.

"That which characterizes our epoch," (says Baron Humboldt in his letter to the President of the Royal Society,) "at a time distinguished, by grand discoveries in optics, electricity, and magnetism, is the possibility of connecting phenomena by the generalization of empirical laws, and the mutual aid afforded by sciences, which had long remained isolated. At the present day, simple observations upon horary declination, and magnetic intensity, made simultaneously, in situations very distant from each other, reveal, so to speak, what passes at profound depths in the interior of our planet, and in the superior regions of the atmosphere. The luminous emanations, the polar explosions which accompany the magnetic storm, appear to follow great changes in the habitual or mean tension of terrestrial magnetism.

"It would tend greatly to promote the advancement of the mathematical and physical sciences, if, under the presidency and auspices of your Royal Highness, the Royal Society of London, to which I make it my boast to have belonged for twenty years, would exert its powerful influence to extend *the line of simultaneous observations*, and to establish *permanent magnetic* *stations*, either in the regions of the tropics on each side of the magnetic equator, the proximity of which, naturally diminishes the amplitude of the horary variations; or in the high latitudes of the southern hemisphere, and in Canada. I venture to propose this latter point, because observations on horary declination made in the vast extent of the United States, are still very rare. Those however of Salem, in 1810, calculated by Mr. Bowditch, and compared by Arago, with the observations of Cassini, Gilpin, and Beaufoy, merit great praise, and might serve as a guide to observers in Canada, in investigating whether the declination does not diminish between the vernal equinox, and the summer solstice, contrary to what occurs in Western Europe. In a memoir that I published five years ago, I suggested as magnetic stations extremely favourable to the progress of our knowledge, New Holland, Ceylon, the Mauritius, the Cape of Good Hope, (rendered illustrious by the labours of Sir John Herschell,) St. Helena, and some point on the eastern coast of America to the south of Quebec. In the last century, in the years 1794 and 1796, an English traveller, Mr. Macdonald, made some new and important observations on the diurnal motion of the needle, at Sumatra and St. Helena, which have since been confirmed and extended on a large scale, in the scientific expeditions of Captains Freycinet and Duperrey, the former having the command of the sloop Uranie, from 1817 to 1820, and the latter, who has six times crossed the magnetic equator, commanding the sloop Coquille, from 1822 to 1825.

"To promote the rapid advancement of the theory of terrestrial magnetism, or at least, to establish with some precision, empirical laws, it is necessary at the same time, to prolong, and to vary the lines of *corresponding observations*, also to distinguish in observations of horary variations, what arises from the influence of seasons, of serene and cloudy weather, and of abundant rains, of the hours of day and night, and of the true time at each place, that is, from the influence of the sun, and of all isochronous influences at different meridians. To these observations of horary declination, must be united those of the annual movement of the *absolute declination* of the *inclination of the needle*, and of the *intensity of the magnetic forces*, the increase of which, from the magnetic equator to the poles is unequal in the western American, and in the eastern Asiatic hemispheres. All these *data*, indisputable bases for a future theory, can only acquire certainty and importance, by the means of establishments, which shall remain permanent for a great number of years; of physical observatories, in which the investigation of numerical elements, may be repeated at set intervals of time, and with similar instruments. Travellers who cross a country in but one direction, and at one epoch, merely prepare the way for an undertaking, which should embrace the complete delineation of the lines without declination, at intervals equally distant: the progressive movements of the points of intersection of the terrestrial and magnetic equators: the changes of form in the isogonal and isodynamic lines: and the influence upon the slow or accelerated movement of the curves, which indubitably arises from the configuration and articulation of the continents. It must be considered fortunate if the *isolated* observations of travellers, whose cause it is my office to plead, have contributed to give animation to a species of investigation, which is the work of centuries, and which requires the concurrence of numerous observers, distributed according to a plan, arranged after mature deliberation, under the direction of several of the great scientific centres of Europe. The directors should not always confine themselves to the narrow limits of the same instructions, but they should vary them freely, in adaptation to the progressive state of physical sciences, and the improvement of instruments, and methods of observation.

"When soliciting your Royal Highness to condescend to communicate this letter to the illustrious society, over which you preside, it is not in any degree my office to enquire which are the magnetic stations that merit preference at the present time, or that local circumstances may admit of establishing. To have solicited the concurrence of the Royal Society of London, will be sufficient to give new life to a useful enterprise, in which I have been engaged for very many years. I venture simply to express the wish, that should my proposition be received with indulgence, the Royal Society would enter into direct communication with the Royal Society of Göttingen, the Royal Institute of France, and the Imperial Academy of Russia, in order to adopt measures the best adapted for the combination of what it may be proposed to establish, with what already exists on a very considerable extent of surface. Perhaps also, measures may be previously concerted for the publication of *partial observations*, and also (if the calculation would not require too much time, and too much retard the communication,) of the *mean results*. One of the happiest effects of civilization, and the progress of reason is, that when addressing learned societies, their willing concurrence may be relied upon, if the object for which it is solicited, tends to promote the advancement of the sciences, or the intellectual development of humanity."

I am happy to see that this spirited letter has received from the Royal Society, that attention which it so justly merits, and that a committee has been appointed for carrying into effect the recommendations it contains. Conformably with the report made by this committee, the ten following places have been fixed on by the council, as being the most eligible for carrying on magnetic observations, according to the plan recommended by Baron Von Humboldt:—Gibraltar, Corfu, Ceylon, Hobart Town, Jamaica, Barbadoes, Newfoundland, Toronto, Bagdad, and the Cape of Good Hope; these places being permanent stations, where officers of engineers and clerks are always to be found. The council also determined that for the present, the observations of magnetism may be limited to those of the direction of the magnetic needle; and the meteorological observations, restricted to those made on the four days, and in the manner recommended in Sir John Herschell's instructions.

A magnetical observatory is now in course of erection at Dublin; the following notice of it was read by Professor Lloyd at the Liverpool meeting of the British Association:

The magnetical observatory, now in progress at Dublin, is situated in an open space in the gardens of Trinity College, and sufficiently remote from all disturbing influences. The building is forty feet in *length,* by thirty in depth. It is constructed of the dark-coloured argillaceous lime stone, which abounds in the valley of Dublin, and which has been ascertained to be perfectly devoid of any influence on the needle. This is faced with Portland stones, and, within, the walls are to be *studded*, to protect from cold and damp. No iron whatever is used throughout the building. With reference to the materials, Professor Lloyd mentioned, that in the course of the arrangements now making for the erection of a magnetical observatory at Greenwich, Mr. Airy had rejected bricks in the construction of the building, finding that they were in all cases magnetic, and sometimes even *polar*. Mr. Lloyd has since confirmed this observation, by the examination of specimens of bricks from various localities; and though there appeared to be great diversity in the amount of their action on the needle, he met with none entirely free from such influence.

The building consists of one principal room, and two smaller rooms, one of which serves as a vestibule. The principal room is thirty-six feet in length, by sixteen in breadth, and has projections in its longer side, which increase the breadth of the central part to twenty feet. This room will contain four principal instruments, suitably supported on stone pillars: viz., a transit instrument, a theodolite, a variation instrument, and a dipping circle. The transit instrument (four feet in focal length) will be stationed close to the southern window of the room. In this position it will serve for the determination of the time; and a small trap-door in the ceiling will enable the observer to adjust it to the meridian. The theodolite will be situated towards the other end of the room, and its centre will be on the meridian line of the transit. The limit of the theodolite is twelve inches in diameter, and is read off by three verniers to ten seconds. Its telescope has a focal length of twenty inches, and is furnished with a micrometer reading to a single second, for the purpose of observing the *diurnal variation*.

The variation instrument will be placed in the magnetic meridian, with respect to the theodolite; the distance between these instruments being about seven feet. The needle is a rectangular bar, twelve inches long, suspended by parallel silk fibres, and enclosed in a box to protect it from the agitation of the air. The magnetic bar is furnished with an achromatic lens at one end, and a cross of wires at the other, after the principle of the collimator. This will be observed with the telescope of the theodolite in the usual manner; and the deviation of the line of collimation of the collimator from the magnetic axis, will be ascertained by reversal. The direction of the *magnetic* meridian being thus found, that of the true meridian will be given by the transit. It is only necessary to turn over the transit telescope, and, using it also as a collimator, to make a similar reading of its central wire, by the telescope of the theodolite. The angle read off on the limb of the theodolite is obviously the supplement of the variation. The use of the transit has been suggested by Dr. Robinson; and it is anticipated that much advantage will result from the circumstance, that the two extremities of the arc are observed by precisely the same instrumental means. With this apparatus it is intended to make observations of the *absolute variation* twice each day, as is done in the observatory of Professor Gauss, at Göttingen,—

the course of the *diurnal variation*, and the hours of maxima and minima, having been ascertained by a series of preliminary observations with the same instrument.

A dipping circle constructed by Gambey, will be placed on a pillar, at the remote end of the room; and will be furnished with a needle, whose axis is formed into a knife edge, for the purpose of observing the diurnal variations of the dip. Gauss's large apparatus will also be set up in the same room, and will be used occasionally, especially in observations of the *absolute intensity*, made according to the method proposed by that distinguished philosopher.

The bars are too large to be employed in conjunction with other magnetical apparatus.

It is intended to combine a regular series of meteorological observations, with those on the direction and intensity of the terrestrial and magnetic force just spoken of; and every care and precaution has been adopted in the construction of the instruments.

The use of bricks in the construction of these observatories, should be particularly guarded against, as, when built into large edifices, they are found, not only to influence the magnetic needle, but to acquire magnetic polarity; this has been observed in the chimneys of factories: the material from which they were made (observes Professor Stevelley) must be largely impregnated with iron: the mud of rivers was the *detritus* from hills, whose rocks are often highly magnetic. The engineers employed in the trigonometrical survey of Ireland, had erected a mound of stones composed of basalt, to sustain the signal staff which they had erected on the highest hill near Belfast; the effect of that heap of stones on the magnetic needle was so great, that in walking round it, the needle would veer round to every point of the compass.

The following description of the apparatus of Professor Gauss, of Göttingen, above alluded to, is extracted from a memoir transmitted to the President of the Royal Society, by the author, in December, 1832, and read before that body in February, 1833:

"Professor Gauss has generally employed needles, (if prismatic bars of such strength may be designated by that name) of nearly a foot in length, weighing each about one pound. They are suspended by an untwisted thread of two and a half feet in length, composed of thirty-two threads of raw silk, and thus able to carry even double that weight without breaking. The upper end of the thread is tortile, and the degree of torsion is measured by means of a divided circle. To the south or north end of the needle, (according as the locality renders either the one or the other more convenient) a plain mirror is fixed, the surface of which, by means of two adjusting screws, may be placed perpendicular to the axis of the needle; but scrupulous attention need not be paid to this adjustment, as any deviation may most exactly be measured by the observations themselves, and taken into account as errors in collimation. The needle thus balanced is enclosed in a wooden cylindrical box, which, besides the small aperture in the lid for the passage of the thread, has a larger one in the side, which is rather higher and wider than the mirror already mentioned.

"Opposite to the mirror, a theodolite is placed, the vertical axis of which is in the same magnetic meridian *with the* thread of suspension, and at a distance from it of about sixteen Parisian feet. The optical axis of the telescope, is placed rather higher than the needle, and inclined in the vertical plane of the magnetic meridian, so as to be directed towards the centre of the mirror on the needle.

"To the stand of the theodolite is fixed a horizontal scale of four feet in length, divided into single *millimetres*; it makes a right angle with the magnetic meridian. That point of the scale which is situated in the same vertical plane with the optical axis of the telescope, and which, for the sake of brevity, may be denominated the zero point, is marked out by a fine thread of gold, depending from the middle of the object glass, and charged with a weight. The scale is fixed at such a height, that the image of a portion of it is seen in the mirror through the telescope, the eye glass of which is adjusted accordingly. At the opposite side from the needle in the same vertical plane, and at a distance from the telescope, equal to that of the image, a mark is fixed, serving at every instant to ascertain the unchanged position of the theodolite.

"It is obvious, that if all these conditions be fulfilled, the image of the zero point on the scale, will appear exactly on the optical axis of the telescope, and that, so far as an object of known azimuth is visible at the place of the theodolite. We may by means of this instrument, immediately find the absolute magnetic declination. If on the other hand, those conditions are only partially fulfilled, then generally speaking the image not of the zero point, but that of another point of the scale will appear on the optical axis; and if the horizontal distance of the scale from the mirror has been measured with exactness, it will be easy to reduce the amount of the divisions of the scale to the corresponding angle, and thus to correct the result first obtained. By turning the needle in the stirrup, (so that the upper surface becomes the lower,) the amount of the error of collimation of the mirror, may be ascertained with great ease and precision. In both the apparatus, one part or division of the scale is equal to nearly 22′, an interval which even the least practised eye, may easily subdivide into ten parts.

" By this mode of operating therefore, the direction of the needle and its variations, are determined with the greatest possible precision. It is by no means necessary always to wait till it is at rest; as the two elongations to the right and to the left, may be observed with great accuracy; and their combination properly managed, will indicate the corresponding point of rest with equal precision. During the anti-meridianal hours, when the daily variation is most rapid, this may be followed almost from one minute of time to the other.

" Of equal importance is this mode of proceeding for observing the duration of the vibrations. The passage of the vertical thread in the telescope, before a fixed point of the scale, (properly speaking the reverse is the case,) may even, if the whole deviation only amount to a few minutes, be observed with such a degree of precision, as never to leave any uncertainty amounting to the tenth of a second in time. The considerable duration of a vibration, (about fourteen seconds in the most intensely magnetised needles) and the slow degrees by which the arc decreases, are productive of other important advantages. Only a few vibrations are required to enable us to determine the time of one vibration with such accuracy, that though the needle be left to itself for one, or even several hours, no doubt will remain on the mind of the observer, as to the number of oscillations performed during the interval of his absence. We may commence with vibrations so small (such, for instance, as those with which we generally leave off,) that the reduction to infinitely small vibrations becomes almost imperceptible; and yet after an interval of six or more hours, the vibrations are still found sufficiently great, to admit of having their beginnings observed with all the requisite precision.

"In cases where anomalies still appear in the observations, which however will prove so trifling, that with the common means they would have been altogether imperceptible, they are solely to be ascribed to the current of air, which, in the locality where the experiments were made, could not be altogether avoided. To remedy this inconvenience, the aperture of the box might be closed by a plane glass; but none perfectly true was within the author's reach, neither could it have been made use of without an inconvenient loss of light.

"To the enumerated advantages of this method another may be added, which is, that the observer constantly remains at a great distance from the needle; while in the old mode of proceeding, his proximity to it was unavoidable; so that even if it were enclosed in a glazed case, it was exposed to the disturbing influence which might be exerted upon it, by the warmth of the body, or of the lamp, by the iron, or even the brass which the experimenter might happen to carry about him.

"The advantages of stout heavy needles over those of diminutive size, which have been made use of for most magnetical observations, particularly those relating to the time of vibration, are dwelt upon by Professor Gauss. He has since successfully employed one weighing upwards of two pounds, and expresses his conviction that if needles from four to six pounds in weight were used, on which slight currents of air would cease to exert any perceptible influence, magnetical observations might attain an exactness and precision unsurpassed by the most delicate astronomical observations. Much stronger threads would indeed be required for suspension, the torsion of which would produce greater reaction; but whatever the strength of the thread may be, the force of torsion must always and may without any difficulty, be taken into account with the greatest exactness.

"The two apparatus may likewise be made use of for another purpose, which, though not immediately connected with the principal subject of the memoir, may still be adverted to. They are the most sensible and convenient *galvanometers*, both for the strongest and weakest energies of the galvanic current. To measure the strongest, it is only required to bring the conducting wire single and at a considerable distance (at least several feet) into the magnetic meridian below or above the needle; for very weak energies a multiplier is wound round the box containing the needle. Some of the experiments were made with a multiplier of sixty-eight circumvolutions, producing a length of wire equal to three hundred feet. No pair of large plates is requisite; a pair of small buttons, or even *simply* the ends of two different metallic wires dipped in acidulated water, produce a current, indicated by the movement of the image along many hundred parts of the scale: but on using a pair of plates of very moderate dimensions, the image of the whole scale, as soon as the circuit is completed, is seen rapidly to dart through the field of vision of the telescope. It is obvious that by this method, the measurement of galvanic forces may be conducted with a degree of care and precision, unattainable by the hitherto employed laborious modes, by means of observed times of vibration; and it is literally true, that by it we are enabled to follow from second to second, the gradual decrease of the intensity of a galvanic current, which, it is well known, is more rapid in the beginning. If, in addition, instead of a single, a double (astatic) needle be used, no degree of electro-magnetic energy will be found too small to admit of being still measured with the utmost precision. Here therefore, a wide field is opened to the naturalist for the most interesting investigations."

Theory of terrestrial magnetism.—Since the earth then is evidently a source of magnetic action, it becomes important to investigate the cause or causes from which it derives its origin, and what the nature of its magnetic condition may be.

Dr. Gilbert first suggested that the earth may contain within itself, and in a position nearly coinciding with its axis of rotation, a powerful magnet; if this were the case, that pole of the magnet which acts in our northern hemisphere, must have a southern polarity, and that pole in the southern hemisphere a northern, the former attracting the north, and the latter the south pole of the needle. The ordinary phenomena of terrestrial magnetism, may, agreeably to this hypothesis, be represented by placing a bar magnet within a terrestrial globe, and holding a small needle suspended by a fibre at different parts of it surface: when held in the northern hemisphere, it will always point to the north end of the enclosed magnet, exhibiting all the phenomena of the variation of the needle as usually observed: at the equator it will have no dip, each pole being equally attracted by the corresponding pole of the enclosed magnet, and at the poles, the dip will be 90°, as observed by Commander Ross, at the northern magnetic pole.

The phenomena of the dip are however more complicated than this hypothesis will allow us to suppose. Some observations of Hansteen, in Siberia, have led him to imagine that there is another magnetic pole in that country, which regulates the magnetic phenomena; in order to reconcile this with the theory of Gilbert, another magnet must be supposed to pass through the globe in the direction of a diameter, whose pole coincides with the Siberian magnetic pole; but even this addition would be inadequate. The theory which has been long gaining ground, is, that the magnetism of the earth, is as that of a *spherical shell of iron,* on which magnetism is induced. In such a mass, and indeed, in every mass of iron, either regular or irregular, solid or hollow, the centres of action are always coincident with the *centre of attraction of the surface of the mass;* whereas, the centres of action in *regular* magnets, are placed *at,* or close to their extremities. The magnetism of the earth, recent and numerous observations have shown, cannot be *explained* by the action of two magnetic poles at a distance from each other, on the contrary, Biot has observed, that the nearer the poles were taken to each other, the greater was the agreement between the computed and observed results; this idea has been adopted by almost every philosopher who has investigated the subject; and the only difficulty is to assign a cause for the induced magnetism. The following are the speculations of Hansteen:

"For these reasons, it appears most natural to seek their origin in the sun, the source of all living activity: and our conjecture gains probability from the preceding remarks on the daily oscillations of the needle. Upon this principle the sun may be conceived as possessing one or more magnetic axes, which, by distributing the force, occasion a magnetic difference in the earth, in the moon, and in all those planets whose internal structure admits of such a difference. Yet allowing all this, the main difficulty seems not to be overcome, but merely removed from the eyes to a greater distance: for the question may still be asked with equal justice, *whence did the sun acquire its magnetic force?* And if from the sun we have recourse to a central sun, and from that again to a general magnetic direction throughout the universe, having the milky way for its equator, we but lengthen an unrestricted chain, every link of which hangs on the preceding link, no one of them on a point of support. All things considered, the following mode of considering the subject seems to me most plausible. If a single globe were left alone to move freely in the immensity of space, the opposite forces existing in its material structure, would soon arrive at an equilibrium conformable to their nature, if they were not so at first, and all activity would soon come to an end. But if we imagine another globe to be introduced, a mutual relation will arise between the two; and one of its results will be a reciprocal tendency to unite, which is designated, and sometimes thought to be explained, by the merely descriptive word *attraction.* Now, would this tendency be the only consequence of that relation? Is it not more likely that the fundamental forces being driven from their state of indifference or rest, would exhibit their energy in all possible directions, giving rise to all kinds of contrary action? The electric force is excited not by friction alone, but also by contact, and probably also, although in smaller degrees, by the mutual action of two bodies at a distance: for contact is nothing but the smallest possible distance, and that moreover only for a few small particles. Is it not conceivable that magnetic force may likewise originate in a similar manner? When the natural philosopher and the mathematician pay regard to no other effect of the reciprocal relation between two bodies at a distance, except the tendency to unite, they proceed logically, if their investigations require nothing more than a moving power: but should it be maintained that no other energy *can* be developed between two such bodies, the assertion will need proof, and the proof will be hard to find.

"I reckon it possible, therefore, that, by means of the mutual relation subsisting between the sun and all the planets, as well as between the latter and their satellites, a magnetic action may be excited in every one of those globes, whose material structure admits of it, in a direction depending on the position of the rotatory axis with regard to the plane of the orbit.

Each of the planets may thus give rise to a particular magnetic axis in the sun: but as their orbits make only small angles with the sun's equator and each other, these magnetic axes would perhaps on the whole correspond with the several rotatory axes. Such planets as have no moons would on this principle, have but one magnetic axis; the rest would in all cases have one axis more than they have moons, if those different axes by reason of the small angles which the orbits of their several moons form with each other, did not combine into a single axis. The conical motions by which the rotatory axes of the planets are carried round the pole of the ecliptic, (the precession in the earth) joined to the revolving motion of the orbits about the sun's equator, (which occasions the present diminution in the obliquity of the ecliptic,) might perhaps, in this case, account for the change of position in the magnetic axis. It would greatly strengthen this hypothesis, if the above great magnetic period, after the lapse of which, both axes again assume the same position, should in fact be found to coincide with the period of the precession, which however seems a little doubtful."

Such were the speculations of Hansteen. But Sir David Brewster has lately proved from an immense number of meteorological observations, that there were in our northern hemisphere, two poles of maximum cold; that these poles coincided with the magnetic poles: that the circle of maximum heat, like the magnetic equator, did not coincide with the equinoctial line; that the isothermal lines, and that the lines of equal magnetic intensity, had the same general form surrounding and enclosing the magnetic poles, and those of maximum cold; and that by the same formula *mutatis mutandis*, we could calculate the temperature and the magnetic intensity of any point of the globe; thus, there can be no doubt that there is a close connection between the phenomena of temperature and magnetism; and since the discovery of Dr. Seebeck, that the mere application of heat to a circuit of two metals is capable of developing magnetic effects, we may consider that we have arrived a step nearer to an explanation of the earth's magnetism, by referring to the sun as the great agent of all these phenomena; but we have yet to discover the metallic thermo-magnetic apparatus by which they are produced.

The electro-magnetic hypothesis was first advanced by the able writer of the article, from which most of the preceding remarks were taken, Sir David Brewster; and Mr. Barlow has, by a beautiful experiment shown its application. It occurred to him, that if he could distribute over the surface of an artificial globe a series of galvanic currents, in such a way that their tangential power should every where give a corresponding direction to the needle, this globe would exhibit, while under electrical induction, all the magnetic phenomena of the earth upon a needle freely suspended above it. The following is an account of the experiment:

"I procured a wooden globe sixteen inches in diameter, which was made hollow for the purpose of reducing its weight, and while still in the lathe, grooves were cut to represent an equator and parallels of latitude, at every 4½° each way from the equator to the poles; these grooves were about one eighth of an inch *deep* and broad; and lastly, a groove of the same *breadth* but of double the depth, was cut like a meridian from pole to pole half round. These grooves were for the purpose of laying in the wire, which was effected thus: the middle of a copper wire nearly ninety feet long, and one tenth of an inch in diameter, was applied to the equitorial groove, so as to meet in the transverse meridian: it was then made to pass round this parallel, returned again along the meridian to the next parallel, and then passed round this again, and so on, till the wire was thus led in continuation from pole to pole.

"The length of wire still remaining at each pole, was bound with varnished silk to prevent contact, and then returned from each pole along the meridian groove to the equator. At this point each wire being fastened down with small staples, the wires for the remaining five feet were bound together to near their common extremity, where they opened to form two points for connecting the poles of a powerful compound voltaic battery.

"When this connection was made, the wire became of course an electric conductor, and the whole surface of the globe was put into a state of transient magnetic induction; and consequently, agreeably to the laws of action above described, a neutralized needle freely suspended above such a globe, would arrange itself in a plane passing from pole to pole through the centre, and take different angles of inclination, according to its situation between the equator and either pole.

"In order to render the experiment more strongly representative of the actual state of the earth, the globe in the state above described, was covered by the gores of a common globe, which were laid on so as to bring the poles of this wire arrangement into the situation of the earth's magnetic poles, according to the best observations we have for this determination; I therefore placed them in latitude 72° north, and 72° south, and on the meridian corresponding with 76° west, by which means the magnetic and true equators cut one another at about 14° east and 166° west longitude.

"The globe being thus completed, a delicate needle must be suspended above it, neutralized from the effect of the earth's magnetism, according to the principle I employed in my observations on the daily variation, and described in the Philosophical Transactions for 1823; by which means it will become entirely under the superficial galvanic arrangement just described. Conceive the globe now to be placed so as to bring London into the zenith, then the two ends of the conducting wire being connected with the poles of a powerful battery, it will be seen immediately that the needle, which was before indifferent to any direction, will have its north end depressed about 70°, as nearly as the eye can judge, *which is the actual dip in London.* If now, we turn the globe about on its support, so as to bring to the zenith, places equally distant with England from the magnetic pole, we shall find the dip remains the same; but the variation will continually change, being first zero, and then gradually increasing eastward as happens on the earth. If again we turn the globe so as to make the pole approach the zenith, the dip will increase, till at the pole itself the needle will become perfectly vertical. Making now this pole recede, the dip will decrease till at the equator it vanishes, the needle becoming horizontal; continuing the motion, and approaching the south pole, the south end of the needle will be found to dip, increasing continually from the equator to the pole, where it becomes again vertical, but reversed as regards its verticality at the north pole."

But although a sphere thus arranged may be made to exhibit the phenomena of terrestrial magnetism, without the aid of any magnetic body, we have yet to learn how such a system of electrical currents can have existence in the earth, unless we refer them to the action of the sun on a metallic thermo-electric apparatus, (see lecture eighth,) distributed over the earth. It would still however remain to be shown what this thermo-electric apparatus is, and where, and how it is distributed.

Whether we seek for a cause of terrestrial magnetism in electrical currents, induced on the earth's surface, or whether we refer it to magnetism induced on the ferruginous matter it contains, or in its atmosphere, we are limited to the *Sun*, if not as a primary cause at least as an agent, to which magnetic phenomena have a distinct reference; future investigation must decide whether it acts by its heat, or by its light, or by specific rays or influences of a magnetic nature. Barlocci and Zantedeschi found that both natural and artificial magnets had their magnetism greatly increased by exposure to common solar rays; a result which could not arise from their *heating* power, as an increase of temperature invariably diminishes the power of magnets.

It is an admitted fact that the *aurora borealis* is a powerful source of magnetism, and that the *south* pole of the needle has a distinct connexion with it. Dr. Dalton, in a work published in 1793, has advanced several ingenious hypothetical views, respecting the cause of the aurora, and its magnetic influence. He says, "the region of the aurora is one hundred and fifty miles above the earth's surface. Immediately above the earth's surface is the region of the clouds, then the region of the meteors, called falling stars and fire-balls, and beyond this region is that of the aurora."*

"We are under the necessity of considering the *beams* of the *aurora borealis* of a *ferruginous* nature, because nothing else is known to be magnetic; and consequently that there exists in the higher region of the atmosphere, an electric fluid partaking of the properties of *iron*, or rather of *magnetic steel;* and that this fluid, doubtless from its magnetic property, assumes the form of cylindrical beams.

"With regard to the exciting cause of the aurora, I believe it will be found in change of temperature. Nothing is known to affect the magnetism of steel: heat weakens and destroys it; electricity does more; it sometimes changes the pole of one denomination to that of another, or inverts the magnetism. Hence we are obliged to have recourse to one of these two agents, in accounting for the mutations above mentioned. As for heat, we should find it difficult, I believe, to assign a reason for such sudden and irregular productions of it in the higher regions of the atmosphere, without introducing electricity as an agent in these productions; but rather than make such a supposition, it would be more philosophical to suppose electricity to produce the effect on magnetic matter IMMEDIATELY. The beams of the *aurora* being magnetic will have their magnetism weakened, destroyed, or inverted, *pro tempore*, by the several shocks they receive during the aurora." In another place he says, "I conceive that a beam may have its magnetism inverted, and exist so for a time, &c." Again, "As the beams are swimming in a fluid of equal density with themselves, they are in the same predicament as a magnetic bar or needle swimming in a fluid of the same specific gravity with itself: but this last will only rest in *equilibrio*, when in the direction of the *dipping needle*, owing to what is called the *earth's magnetism;* and as the former also rests in that position only, the effects being similar, we must, by the rules of philosophising, ascribe them to the same cause. Hence then it follows, THAT THE AURORA BOREALIS IS A MAGNETIC PHENOMENON, AND ITS BEAMS ARE GOVERNED BY THE EARTH'S MAGNETISM. I am aware that an objection may be stated to this; if the beams be swimming in a fluid of equal density, it will be said they ought to be drawn down by the action of the earth's magnetism. Upon this I may observe, that it is not my business to show why this is not the case, because I propose the magnetism of the beams as a thing demonstrable, and not as a hypothesis. We are not to deny the cause of gravity, because we cannot show how the effect is produced. May not the difficulty be removed by supposing the beams of *less* density than the surrounding fluid?"

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* Dr. Dalton adduces in proof of the great height of the aurora its extremely attenuated light, which he says, may spread over one half of the hemisphere, and not yield more light than the full moon; this he says arises from the extreme rarefaction of the air.

Lastly, although it has been clearly proved that a source of magnetism does exist in the atmosphere, yet it may be asked if there is any reason for believing that the magnetism in the atmosphere is strong enough to be considered as the *only* source of terrestrial magnetism. It has been shown by M. Arago, that the auroræ which exist only at St. Petersburg, in Siberia, and even in North America, actually disturb the magnetic needle at Paris; and he considers it highly probable that the auroræ even round the south pole of our globe, extend their influence to Paris. Sufficient however has, I think been said, to show, that many more enquiries are wanting, before the question as to the true cause or causes of terrestrial magnetism can be satisfactorily answered.

LECTURE VII.

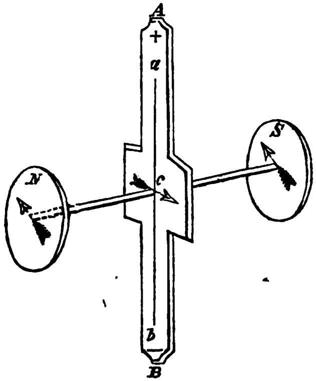
ON ELECTRO-MAGNETISM.

THE disturbance produced in the magnetic needle by the aurora borealis and lightning, had long suggested to philosophers that the agencies of electricity and magnetism must be connected by some close and intimate relation. For nearly half a century the discovery of this relation was a favourite object of speculation; and it is curious to compare the various opinions which were maintained by different experimentalists. Magnetic properties were easily communicated to bars of steel, by passing strong electrical shocks through them, but no general law could be traced as governing the polarity thereby imparted. D'Abilard imagined, that he had proved that the electric discharge imparts a northern polarity, to that point of a steel bar at which it enters, and a southern polarity to that at which it makes its exit: and this quite independently of the position of the needle, with respect to the magnetic poles of the earth. Wilke, on the other hand, was equally satisfied that an invariable connexion exists between the negative electricity, and the northern polarity.

In one of the essays (which received a prize) on the question proposed by the electoral academy of Bavaria, in 1774, "Is there a real and physical analogy between electric and magnetic forces; and if such analogy exists, in what manner do these forces act on the animal body?" Professor Van Swinden, of Franeker, after a long and elaborate discussion of the subject, arrived at the conclusion, that the similarity between electricity and magnetism, amounts merely to an *apparent* resemblance, and does not constitute a true physical analogy; whence he infers that these two powers are essentially different and distinct from each other. On the other hand, Professors Steiglehner and Hubner, maintained that both classes of phenomena are referable to the *same* agent, varying only in consequence of a diversity of circumstances. In this unsettled state, the subject remained till some years after the discovery of galvanism, by which a fresh field of enquiry was opened, and a means of maintaining a large and continuous current of electricity obtained. The first approach to a solution of the question, was the publication of Ritter; he asserted, "that a needle, composed of silver and zinc, arranged itself in the magnetic meridian, and was slightly attracted and repelled by the poles of a magnet:" he also stated, "that by placing a gold coin in the voltaic circuit, he had succeeded in giving to it positive and negative electric poles; and that the polarity so communicated, was retained by the gold, after it had been in contact with other metals, and approved therefore to partake of the nature of magnetism. A gold needle, under similar circumstances, acquired still more decided magnetic properties;" and, "that a metallic wire, after being exposed to the voltaic current, took a direction, N.E. and S.E."

In consequence of the vague and loose manner in which Ritter advanced his speculations, but little notice was taken of them, and no satisfactory results were obtained, till the year 1819, when Professor Oersted, of Copenhagen, made his famous discovery, which forms the basis of the science of electro-magnetism. The fact observed by Oersted was, that when a magnetic needle was brought near the connecting medium, (whether a metallic wire, or charcoal, or even saline fluids, of a closed voltaic circle,) it was immediately deflected from its natural position, and took up a new one, depending on the relative position of the needle and wire. If the connecting medium was placed horizontally *over* the needle, that pole of the latter which was nearest to the *negative* end of the battery, always moved *westward*; if it was placed *under*, the same pole moved to the *east*. If the connecting wire was placed parallel with the needle, that is, brought into the same horizontal plane in which the needle was moving, then no motion of the needle in that plane took place, but a tendency was exhibited in it, to move in a verticle circle, the pole nearest the *negative* side of the battery being depressed when the wire was to the *west* of it, and elevated when it was placed on the *eastern* side. As in all electro-magnetic researches, it is necessary to bear in mind these affections of the needle and electrified wire; several contrivances have been made to assist the memory respecting the details. *Fig.* 79 represents the plan of Dr. Roget. A B is a slip of card, on each side of which, a line *a b* is drawn along the middle of its length, the end *a* being marked x, the end *b* —, and the centre *c* being crossed by an arrow, at right angles to it, directed as in the figure. Through the centre, and at right angles to the plane of the slip of card, there is made to pass, a slender stem of wood, at the two ends of which, are fixed in planes, parallel to the slip of card A B, the circular discs of card marked respectively with the letters N and S, and with arrows parallel to, but pointing in a contrary direction to the one at *c*. The same marks must be put on the reverse of each of the three pieces of card, so that when held in different situations they may be seen without turning the instrument.

Fig. 79.



If the line *a b*, be supposed to represent the connecting wire, (the direction of the current of electricity being denoted by the signs x and — at the ends of the line) the arrow at the centre will point out the direction in which it tends to move, when under the influence of the north pole of a magnet, situated at N; or of a south pole situated on the other side, as at S; and vice versâ the arrows N and S, will indicate the directions in which the north and south pole respectively, tends to revolve round the connecting wire in its vicinity, with relation to the direction of the current of electricity, that is passing through it. It must be observed that the poles N, S, are not considered as in connexion with each other, or as forming parts of one magnet; their operations are exhibited singly and quite independently of each other. The advantage of the instrument consists in its being capable of being held in any situation, and thus easily adapted to the circumstances of any fact or experiment of which we may wish to examine the theory.—*Brande's Chemistry*.

A useful help to the memory has also been suggested by Ampère. Let the observer regard himself as the conductor or connecting wire, and imagine a positive electric current to pass from his head towards his feet in a direction parallel to the magnet; then its north pole in front of him will move to his right side, and its south pole to his left. The plane in which the magnet moves is always parallel to the plane in which the observer supposes himself to be placed. If the plane of his chest be horizontal, the plane of the magnet's motion will be horizontal; but if he lie on either side of the horizontally suspended magnet, his face being towards it, the plane of his chest will be vertical, and the magnet will tend to move in a vertical plane.

The extent of the declination of the magnetic needle depends entirely on the *quantity of electricity* passing along the connecting wire, and has nothing to do with the *tension* of that electricity, nor is it increased by increasing the intensity of the current; hence the employment of galvanic batteries for the exhibition of the effects of electro-magnetism; and hence also the reason why the first enquirers were foiled in their attempt to elicit these effects.

That the conducting wire is capable of attracting and repelling the poles of a magnet, may be proved by the following experiment:—suspend horizontally a magnetic needle, and place it near the connecting wire of a closed circle, held *vertically* and at right angles to it; the positive current being supposed to flow upwards. When the wire is exactly midway between the poles of the needle, no effect will be produced, but on moving it about half-way to the north pole, it will be attracted; still continue to advance it, and when it reaches the extremity of the north pole, it will be repelled. Similar effects occur on advancing the wire towards the south pole. If the current of electricity be made to *descend* the wire, or if the needle be placed on the *eastern* side of the needle, the current ascending, equal but opposite effects will be observed; then, repulsion will first take place, and afterwards attraction.

From the manner in which the needle is affected, when placed parallel to either side of the electric current, it was inferred that a *current of magnetism* is set in motion at right angles to the latter. This was termed by Dr. Wollaston *vertiginous* magnetism; and by Mr. Barlow, the magnetic force was said to exert a *tangential action.*

The figures 80 and 81, will represent the direction of the circulating current of magnetism. In *Fig.* 80,

Fig. 80.

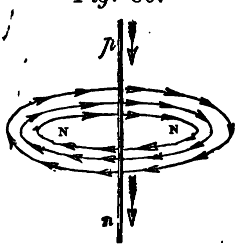
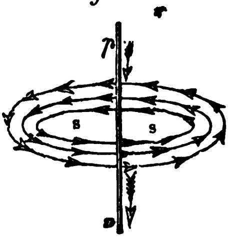


Fig. 81.

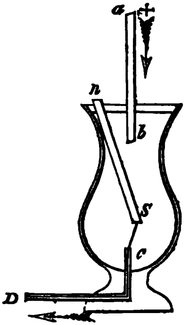


the connecting wire is placed vertically, and the electric current is descending through it from *p*, to *n*; the arrows denote the direction in which the north pole of a magnet will have a tendency to move round it, i. e., from left to right, or in the direction of the hands of a watch. *Fig.* 81 shows the motion impressed on the south pole by a similar current. When the direction of the electricity is reversed, the wire still preserving its vertical position, the direction of the action is also reversed.

Reasoning on these relative motions of the needle and electrified wire, Dr. Faraday conceived that the pole of a magnet ought to revolve about the conductor, and the conductor about the pole of a magnet, and by the following ingenious apparatus he succeeded in proving this to be the case.

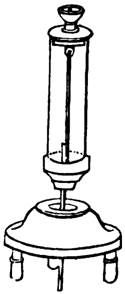
Into the centre of the bottom of a cup, as in the vertical section *Fig.* 82, a copper wire *c*, D, was inserted, a cylindrical magnet *n*, *s*, was attached by a thread to the copper wire *c*, and the cup was nearly filled with mercury, so that only the north pole of the magnet projected. A conductor, *a*, *b*, was then fixed in the mercury, perpendicularly over *c*. On connecting the conducting wires with the opposite ends of the battery, a current was transmitted from one wire, through the mercury, to the other. If the positive current descended, the north pole of this magnet immediately began to rotate round the wire, *a*, *b*, passing from east through the south to west, i. e., in the

Fig. 82.



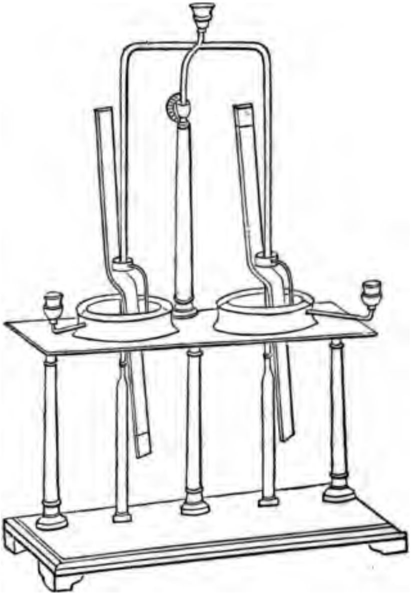
direction of the hands of a watch; but if the current ascended, the line of rotation was reversed. Conversely, a magnet was fixed in a vessel of mercury, and the conducting wire hung from a hook above it, the end just dipping into the fluid; the electric current being then transmitted through the moveable conductor, Faraday found that the free extremity instantly began to revolve round the pole of the magnet, in a direction similar to the last. A good contrivance for exhibiting this is shown in *Fig.* 83.

Fig. 83.



In order to obviate the necessity of employing so much quicksilver, which, by the resistance which it offers to the revolution of the magnet, greatly diminishes the velocity of the rotation, the apparatus in *Fig.* 84, has been devised by Mr. Watkins. It exhibits the contrary poles of two magnets rotating about two electrified wires. Two flat bar magnets doubly bent or curved in the middle of each, and having under the inverted part of each, an agate cup fixed, by which it is supported upon an upright pointed wire, affixed in the basis of the apparatus, and upon which it turns round as upon an axis. Above the agate cups, cisterns to hold mercury are also formed. Two circular troughs to contain mercury, are supported upon a stage, affixed to the basis, having holes in their centres, to allow the magnets to pass through them. A bent pointed wire is affixed into the cisterns of each magnet, the ends of which dip into the mercury contained in the troughs upon the stage; and through the sides of the trough, wires are passed, entering into the mercury contained in the troughs, and bearing at their ends other cups to hold mercury. To steady the motion of the magnets, wire loops are affixed to them, which embrace the upright pointed wires on which the magnets rest. A hollow pillar is firmly affixed to the stage, in which a bent wire supporting another cross wire is inserted, and is capable of being raised or lowered, and secured at any required height by a binding screw. The two ends of the cross wire are bent downwards and pointed, and made to enter the two small

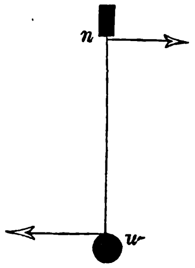
Fig. 84.



cisterns affixed upon the magnets. A third cup to contain mercury is also provided at the top of the cross wire, and a communication being made with the battery, by means of uniting wires dipping into the mercury in the cups, the wire from the positive end of the battery being placed in the upper cup, and the wire from the negative end in each of the lower cups, the magnets will begin to rotate in opposite directions, and those directions may be reversed, by changing the situations of the uniting wires. Two batteries should here be employed, in order to make both the magnets revolve with the desired velocity; and attention must be paid, when using two batteries, that the currents of electricity flow in the same direction; otherwise the phenomena of the revolutions of the magnets in contrary directions will not take place, but they will both revolve in the same direction.—*Popular Sketch of Electro-Magnetism by Francis Watkins.*

Thus it will be seen that the direction of the rotation imparted by a fixed current to a moveable pole, will be the same as that which the same pole imparts to the same current. Suppose *w*, *Fig.* 85, to represent a section of a conducting wire, along which a positive current is descending, and *n* the north pole of a magnet. The influence of *w* on *n* will be to impel it in the direction of the arrow; but *n* will also re-act on *w*, and tend to produce in it an opposite direction, as exhibited by the arrow attached to *w*. Each is disposed to describe

Fig. 85.

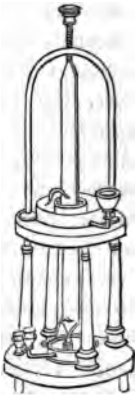


a circle round the other, moving in the same direction as the hands of a watch; and if *w* and *n* were at liberty equally to move, they would have a tendency to rotate round the line between them.

Ampère first succeeded in effecting the rotation of a magnet, round its own axis. In his original experiment, the magnet was allowed to float, without a support, in a vessel of mercury, being kept in a vertical position, by a weight of platina attached to its lower end. The object was, to make the electrical current pass through one half of the magnet itself, and then to divert it from its course, and make it pass away in such a direction, as that it should not affect the other half. The reason of this is evident: suppose a positive current be made to descend a magnet placed vertical, its north pole being uppermost, it would tend to urge that pole round from left to right; but its influence on the south pole, would be just the reverse, tending to urge it from right to left; or if two electrical currents be supposed, corresponding to the vitreous and resinous, the tendencies would be the same; and here it may be as well to mention, that in describing the phenomena of electro-magnetism, I shall, to avoid tediousness, adopt the language of a single fluid, and suppose, that in the connecting wire of a voltaic battery, the electrical current is passing in one stream, from the positive to the negative end.

In Ampère's experiment, the electric current, after traversing the upper half of the magnet, passes into the mercury, and being diffused through it, acts in no sensible degree on the lower half, and does not interfere with the rotation produced by its influence on the upper pole.

Fig. 86.



It is, however, better to carry off the current by a different channel, and this is effected by adopting the form of apparatus, shown in *Fig*. 86. It is thus constructed by Mr. Watkins A flat bar magnet is supported in a vertical position, by an upright metal wire, affixed in the basis of the apparatus, and having a hole in its centre, containing an agate cup, to receive the lower pointed end of the magnet; its upper end turns in another hole, made in a vertical screw, with a milled head to turn it by, which is passed through a screw hole, made in an arched piece of wire, affixed to the upper part of the basis. Around the first mentioned vertical wire, a cistern to contain mercury is provided; and another, having a hole in its centre, to allow the magnet to pass through, and revolve within it, near the middle of the magnet. These cisterns have metal wires projecting into them, through their sides, to support cups which contain mercury, to effect the communication with the voltaic battery, by means of uniting wires. Into the magnet, two small bent and pointed wires are affixed, the ends of which dip into the mercury, contained in the cisterns. When the voltaic circuit is complete, the magnet begins to rotate within the electricity, which it conducts itself, as it in fact forms part of the circuit; the rapidity of the revolutions of the magnet, depending upon the delicacy of the sustaining point, the strength of the magnet, and the power of the battery employed. If it be desired to actuate a large magnet, it is necessary an addition to the apparatus should be made, by providing a cup, affixed to the vertical screw, to contain mercury, by which contrivance, and by employing an additional battery, a current of electricity can be passed from the top of the magnet to its equator; and as in the first mentioned case, an opposite current can be passed from its lower end to the equator; an additional force is obtained. The current from the second battery must of course be sent along the upper half of the magnet, in a direction contrary to that which passes through the lower pole; but since the rotatory force is proportional to the power of the voltaic battery employed, it is probable that the second battery would be equally efficacious, if it were employed in increasing the strength of the first, by being joined to it. The ends of the wires should be amalgamated, by rubbing them first with nitrate of mercury, and then dipping them into the clean metal.

Fig. 87.

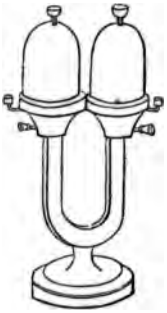


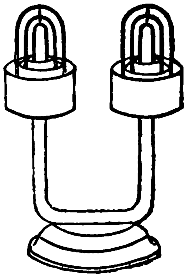
Fig. 87 represents an apparatus to exhibit the rotation of a conducting body round its own axis, and is exactly the converse of the last experiment. In the former case, the electric current was applied in the interior of the magnet, but here means have been devised for procuring the action of the magnet, from the interior of the conducting body. In the place of the wire, therefore, a hollow metallic cylinder is employed, in the axis of which, the influencing magnet can be placed. Mr. Barlow devised this instrument, and the figure shows the arrangement on a horse-shoe magnet, by Mr. Watkins, (see his sketch, page 74.) A horseshoe magnet is supported vertically upon a stand, having holes formed in the centres of its ends. Two wooden circular troughs are secured by binding screws upon the arms of the magnet, to contain mercury. Into the holes in the centres of the ends of the magnet, two conical pointed wires are inserted, which are affixed in the middle of two hemispherical cups, united to cylinders, the rims of which are formed into points, which are dipped into the mercury, contained in the circular troughs. Upon the top of each hemisphere, is placed a small platina cup, to contain mercury. Other cups for holding mercury, are supported on the external ends of bent wires, which pass through the sides of the circular troughs, into the mercury, contained therein. When a stream of voltaic electricity is passed through this apparatus, by means of connecting wires, placed in the mercury, contained in the upper and lower cup, the cylinders commence revolving in opposite directions, that cylinder on the north pole, and down which the current is descending, moving of course from left to right; but if the two upper cups be united by a wire, and the lower cups connected with the positive and negative extremities of the voltaic battery, the same stream will traverse both sides of the apparatus, passing upwards in one cylinder, and downwards in the other; and the rotations will now, from the contrary influences of the two poles, be in the same direction in both cylinders.

Dr. Faraday has shown, that the results in this last experiment, are the same when the magnet and conductor are united together; for, on fixing a thin piece of wood on the upper end of a magnet, loaded at its lower extremity with a platina weight, and floating in a vessel of quicksilver, and attaching to the wood an arch of strong wire, the whole apparatus commenced revolving, on the transmission of the electric current through it; on the other hand, when a hollow cylinder of metal, was balanced on a vertical axis of wood, and acted on by the poles of a magnet, placed *outside*, the rotatory force was very feeble. This affords us a means of explaining the circumstances of the rotation of a magnet, about its own axis; for the explanation of that experiment, will very much depend on the course, which the current of electricity is supposed to take, in its passage through the magnet. If it be supposed to pass through the interior, along the axis of the magnet, it would then occasion rotation, by its influence on the parts of the magnet, that are situated nearer the surface; but if the course of the current be supposed to be along the surface, it will itself be influenced by the polarity of those portions of the magnet which lie near the axis, and the rotatory tendency impressed upon it will produce the rotation of the magnet, which will, of course, be carried along with it. This, it will be seen, corresponds with the rotation of a conducting body round its own axis, a magnet being in the centre; and it has been shown above, that the circumstance of the magnet and conductor being immoveably joined, makes no difference in the results.

Another fact is made apparent by this last experiment, which is, that the electro-magnetic influence of the conductor, takes place, equally, when the electrical current is diffused over a considerable surface, as when it is concentrated in a single wire; in the cylinder, every filament of which it is composed, may be supposed to conduct its share of the current, and thus contribute towards the general effect.

A magnetic needle, is found to be influenced by the current of electricity, that is passing through the voltaic battery, from its *positive* to its *negative* pole, as well as by the wire that completes the circuit; or, in other words, every part of the circuit exhibits the same electro-magnetic properties; and, as action always implies an equal and corresponding re-action, the magnet may be supposed to have a tendency to move the battery, equal to that which the battery has to move it. This tendency was first actually exhibited, by a very ingenious contrivance of Ampère, and which Mr. Watkins has applied to each of the poles of a horse-shoe magnet, as shown in *Fig.* 88. It consists of a horse-shoe magnet, firmly fixed to a stand, at its bent part; its two ends being made round, and having a small hole in the centre of each, at the bottom of which hole, an agate cup is placed, and in which, pointed wires fixed to the parts presently to be described, are made to revolve. A double cylindrical copper vessel, having a bent metal wire, fixed to the top of its innermost cylinder, with a vertical wire pointed at both ends, fixed in the middle of that bent wire, is hung upon the upper end of each pole of the magnet, the lower points of the vertical wires of each vessel, entering the

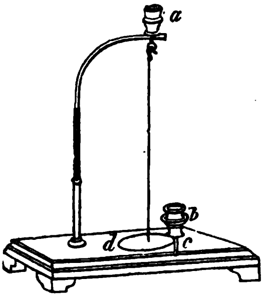
Fig. 88.



holes, formed as above described, in the magnet for that purpose. Two hollow cylinders of zinc, each furnished with similar bent wires, having holes made in the under sides of each, are then placed within the double copper vessels; the holes in the bent wires, being hung upon the uppermost pointed ends of the vertical wires, before mentioned. Diluted acid being then poured into the space between the copper cylinders, the voltaic action commences, and presents the phenomena of the whole of the four cylinders revolving upon their axes, the copper vessels revolving in opposite and contrary directions, and the zinc cylinders turning in opposite directions to them; the rapidity of their revolutions depending upon the strength of the acid, and the delicacy of their suspension.*

Numerous amusing experiments, have been devised, for exhibiting the vibratory tendencies of electrified wires, when under the influence of magnets. *Fig.* 89 represents an arrangement of Mr. Marsh. It consists of a slender wire, suspended from a loop, and capable of free motion; its lower end is amalgamated, and dips into a small cistern of mercury; the cups *a* and *b*, are filled also with mercury, and through them the electrical current is passed down the loose wire; no motion of

Fig. 89.



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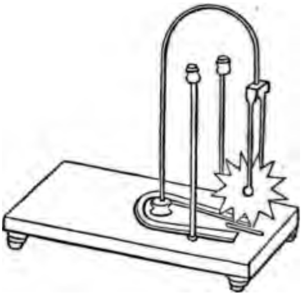
* The zinc cylinders revolve with great rapidity, but from the superior weight of the copper cylinders, when filled with the exciting liquor, it is rarely that the rotatory tendency can be exhibited in them.

this wire is perceptible, until a horse-shoe magnet is placed in a horizontal position, on the basis, with its poles enclosing the wire, when it is instantly urged either forwards towards *c*, or backwards towards *d*, according to the position of the poles, and the direction of the current. In either case it is thrown out of the mercury, and the circuit being thus broken, the effect ceases, until the wire falls back again, by its own weight, into the mercury; when the current being re-established, the same influence is again exerted, the phenomenon is repeated, and the wire exhibits a quick succession of vibratory motions.

This vibratory motion, is easily converted into one of rotation, by employing a spur wheel, as in *Fig*. 90. The radii of the wheel, must be so arranged, that each ray shall touch the surface of the mercury, before the preceding ray shall have quitted it. The direction of the motion depends of course on the same circumstances, as were before mentioned.

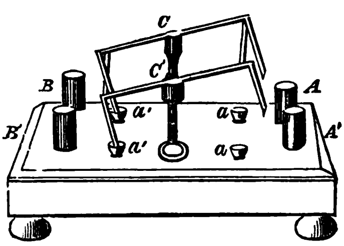
Fig. 90.



This forms a very brilliant experiment, when a powerful battery, (such as that shown in *Fig*. 20,) and a strong magnet, are employed. The wheel revolves with immense velocity, and streams of sparks of a green colour, arising from the combustion of the copper points of the radii of the wheel, are thrown sometimes over the cups of the instrument.

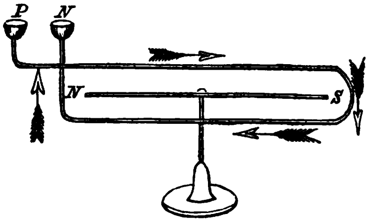
By altering the direction of the electrical current, all the vibrations and rotations that have been above described, are reversed; this alteration, may be easily and elegantly effected, by employing a little instrument, constructed by Mr. E. M. Clarke, which he calls his electrepeter; it is shown in *Fig*. 91. The cups *a*, *a*, *a′*, *a′*, communicate with wires underneath the stand, as also the larger cups, A, A′, B, B′, which are intended to convey the electrical current, from the voltaic battery, to the machine to be set in motion. Suppose the bent points of the arms *c*, *c*, to be in the position, represented in the figure, and that the electrical current is passing from A to B, and back again, through the spur wheel, *Fig*. 90, from B′ to A′, by merely pressing the other extremities of the arms, into their respective cups *a′ a′*, the direction of the current is instantly changed, it now being from A, through the wires underneath the stand, to B′, and back from B to A; or the passage of the current may be arrested altogether, by keeping the arms in a horizontal position. The great use of this instrument, consists in its enabling the experimentalist, to change the direction of the electrical current, with rapidity, without being obliged to derange his apparatus, by removing and re-arranging the conducting wires, by hand.

Fig. 91.



We have now seen abundant instances of the mutual action of electrical currents and magnets on each other, and referring to the first experiment of Oersted, it will be remembered, that a positive current, passing horizontally over the needle, from north to south, has a tendency to cause the north pole to move to the east; consequently, if another current be made to pass under the wire, from south to north, the needle will be affected with twice the force that a single wire would have exerted; or, what s the same thing, a continuous wire, may be bent back on itself, as in *Fig*. 92, and this constitutes the simplest form of the galvanometer. The current, passing in opposite directions, above and below the needle, will conspire, in both cases, to deflect it from its natural position, and in the same direction, and to bring it into a position nearer to right angles to the plane of the wires.

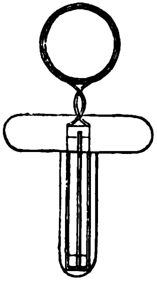
Fig. 92.



If instead of a rectangle, the wire be supposed to be bent into a circular form, the pole of a magnetic needle, placed in the centre, or in a line passing through the centre, would be impelled in one uniform direction, by the electric current, transmitted through the wire, and could the current move in a perfect circle, from right to left, the north pole of a magnet, placed in the centre, would move to the right, and the south pole to the left. If the north pole of a magnet, therefore, were presented to the right hand side of this circular current, it would tend to move away from it, having the appearance of being repelled; just the contrary would happen, if the south pole of a magnet were presented on the same side, that is, there would be the appearance of a mutual attraction between them. But when either of these poles is presented on the other side of the plane of the circular current, effects of an opposite kind are produced; the north pole appears to be attracted, and the south pole to be repelled.

Now, since a similar and reciprocal action takes place between the magnetic pole and the electric current, the latter, together with the wire that conveys it, will, if at liberty to move, recede from the north pole, or appear to be repelled by it, or advance towards the south pole and appear to be attracted by it. *Fig.* 93 represents the very ingenious apparatus invented by M. De la Rive, for exhibiting this reciprocal action. It consists of a glass cylindrical vessel, having a cork float attached to its upper end. Into this vessel is inserted a small voltaic combination, formed on Dr. Wollaston's plan, and consisting of a plate of zinc surrounded by a copper plate, the zinc plate being insulated upon its edges. A copper wire affixed by soldering to both these plates, is made into the form of a ring, consisting of several coils of the wire, which is besides insulated, by being wrapped round with silk thread: upon pouring diluted acid into the glass vessel, and placing the plates in it, voltaic action commences, and is manifested by placing the apparatus afloat in water, when the coil will have a tendency to take a position in the plane of the

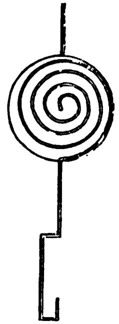
Fig. 93.



magnetic meridian, and will exhibit all the effects of the attractive and repulsive tendencies which have been described above, when a strong bar magnet is brought near it on either side. If the magnet be sufficiently slender to pass through the ring, the following curious phenomenon will be observed :—If the pole be presented to it on the side where attraction takes place, the ring will move towards it till it arrives at the pole, and then proceed onwards in the same course, the magnet being held in the axis of the ring, till it reaches the middle of the magnet, but there it seems inclined to stop; and then, after a few oscillations, it settles as in a position of equilibrium; for, if purposely displaced, by bringing it forwards towards the other pole, it returns with a force which shows that it is repelled from that other pole. Let the magnet now be withdrawn, and turning it half round, so that its poles are in directions the reverse of what they were at first, and holding the ring in one hand, let the magnet be again introduced into it with the other hand, until it is half way through. Under these circumstances, it is just possible that it may have been brought into such a situation as that the ring may again be in equilibrium, undetermined in what direction to move; but the slightest change in this position, causes it to move with an accelerated velocity towards that pole which is nearest to it; and getting entirely clear of the magnet, it is projected to a considerable distance from it. At length, however, it stops, and, gradually turning round, presents the opposite face to the magnet; attraction now takes place, and the ring returns to the magnet with a force equal to that with which it had before fled from it; and passing again over its pole, finally rests in its position of equilibrium, encircling the middle or what may be termed the equator of the magnet. In the former position it was equally attracted by the two poles of the magnet, in the latter it is equally repelled; and accordingly, the first was an unstable and the last a stable equilibrium.—*Treatise on Electro-magnetism in the Library of Useful Knowledge, by Dr. Roget.*

The directive tendency of an electrified wire, may be still more strikingly exhibited, by bending it into the form of a spiral, and either connecting it with the floating galvanic arrangement, or suspending it delicately by a hook, as in *Fig.* 94, and passing the voltaic current through it, the plane of the spiral will be found to place itself east and west, the positive current ascending on the west side, and descending on the east; taking the same course as the hands of a watch, when it is held on edge, with the plane of the dial lying east and west, facing south. That side of the spiral which is towards the north, acts as the north pole; and the south side has an opposite polarity. *Each side powerfully attracts iron filings.*

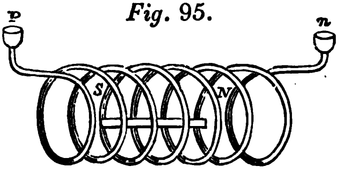
Fig. 94.



But a still closer imitation of a magnet is obtained by making a voltaic conductor into the form of a helix, as in *Fig.* 95, which was done by Arago, at the suggestion of Ampère. A needle placed in the axis of this helix, becomes fully magnetised in an instant; for in this arrangement, the current nearly in every part of its course, is at right angles to the needle, and as each coil adds its effect to that of the others, the united action of the helix is very powerful.

The polarity given to the needle depends on two circumstances, first, the direction of the current with reference to the axis of the helix; and, secondly, the direction in which the helix is turned, which may be either in the form of a right handed screw, the turns proceeding downwards from right to left, or, of a left handed screw, the turns proceeding in a contrary direction. And if the current be descending on the side next to the spectator in the horizontal helix, (*Fig.* 95,) the north pole of a magnet in the axis will be determined to the right, and the south pole to the left, and this tendency will be given in the right handed helix, if the current be transmitted through it from left to right, but in the left handed helix from right to left. If a glass tube be thus surrounded by a coil of wire, and traversed by the electric current, its action on a small magnetised needle will be so powerful, that when placed within it, it will actually start up and remain suspended in the air, in opposition to the force of gravity; and this will sometimes take place even in a vertical position of the helix.[*]

Fig. 95.



Thus then, a heliacal conductor may be regarded as a *magnet*, as long as the electric current is passing through it; and it was fully demonstrated by Ampère, soon after the discovery of Oersted, that exactly what d be anticipated from the magnetic influence of uctors, takes place, for two voltaic conductors, or portions of the same conductor attract each other ı the currents have the same direction, and are ıally repulsive, when traversed by opposite cur- s. Thus in two parallel :ive currents , and C D, 96, which in the same :tion, the contiguous sides are affected with an ›site polarity, one being south, and the other h; whereas, he two con- y currents, , and G H, . 97, the ad- nt sides have same polarity, and therefore repel each other. ilarly, when two currents cross each other, as A B, , *Fig.* 98, it bvious that at of the four cor- , A D and C B, lar poles are :iguous; while he other cor- different poles :ur. Hence wires tend to lve round E, and place themselves parallel to the ents, so that both may flow in the same direction. *'urner's Chemistry.*

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[*] In order to exhibit this curious experiment, it is necessary to employ a helix of small internal diameter, and consisting of at least six strands of insulated copper wire.

Fig. 96.

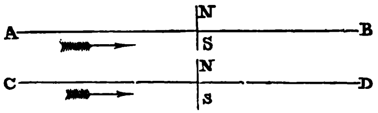


Fig. 97.

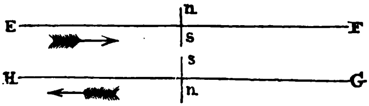


Fig. 98.

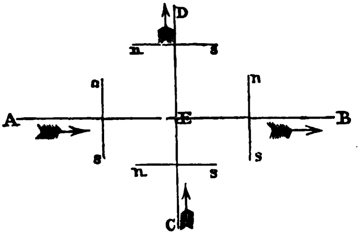
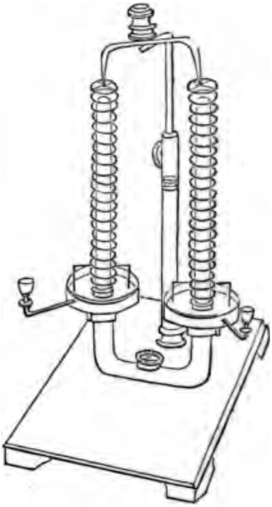


Fig. 99.



Mr. Watkins has contrived the apparatus shown in *Fig.* 99, for exhibiting the rotation of heliacal conducting wires round the poles of a magnet. It consists of a horse-shoe magnet, firmly screwed to a wooden basis or support; two heliacal coils of copper wire, having slender bars across their tops, with needle points in their centres, turning in conical holes, drilled in the ends of the magnet, and above the points, two small platinum cups, to hold a globule of mercury in each. Two wooden cisterns are attached by screws on the lower parts of the magnet, having bent arms fixed in them. To the lower ends of the heliacal coils are soldered slender pointed wires, bent so as to enter slightly into mercury, placed in the two larger cups, mercury being also placed in the small cups. A brass standard affixed to the basis of the apparatus, has a forked piece attached to it, with two points descending into the two platinum cups upon the tops of the coils: and there is also another cup placed upon the forked piece to contain mercury. The voltaic circuit is completed by placing wires in the mercury contained in the small side cups, and connected with the copper parts of the battery: and other wires communicating with the zinc parts, are placed in the cup on the top of the apparatus. When the electric stream flows through the apparatus, the heliacal coils revolve rapidly in opposite directions; but on changing the disposition of the connecting wires, the revolutions of the coils will be reversed. The points of the various wires must be very clean and amalgamated, and the mercury in the cisterns and cups free from dirt.—*Popular Sketch of Electro-Magnetism, p.* 78.

Instead of a helix, the rotatory action of a magnet on a conductor, may be exhibited by employing a light wire frame, the rapid revolution of which may be effected by a very feeble voltaic power, in consequence of its levity.

When soft iron is submitted to the influence of a continuous electric current, its magnetic properties are very powerful, although it does not retain them; but a steel needle, as was observed above, becomes instantaneously and permanently magnetic, when introduced into the axis of the spiral conductor. It was discovered nearly at the same time by Sir H. Davy and M. Arago, that the connecting wire of a voltaic battery was attractive of iron filings, while the electric current was passing through it; and in one experiment, in which a battery of one hundred pairs of four inch plates was employed, the filings adhered in such quantities as to form a mass ten or twelve times the thickness of the wire. It was also found that the intensity of the induced magnetism, depended on the quantity of electricity transmitted through the wire in a given time. Hence a wire electrified by a common electrical machine, however powerful, produces no sensible effect; a feeble magnetism only is obtained by the reception of large sparks; but on passing the discharge from a Leyden battery through the wire, the needles placed transversely to the wire are rendered permanently magnetic. The discharge of an electrical battery of seventeen square feet highly charged, through a silver wire of the twentieth of an inch in thickness, rendered bars of steel two inches long, and from one-twentieth to one-tenth of an inch in thickness, so magnetic, as to enable them to attract small pieces of steel wire or needles; and the effect was communicated to a distance of five inches below or above laterally from the wire through water, or thick plates of glass or metal electrically insulated.

In order to produce the greatest effect of electro-magnetic induction on soft iron, the current from the battery must be made to envelop it, by passing through a considerable length of insulated copper wire wound round the iron; but since a great length of wire is found to diminish the influence of the current, as has been proved by Professor Cumming, Barlow, and Ritchie, it is better that the total length of wire intended to be used, should be cut into several portions, each of which, covered with silk or cotton thread, to prevent lateral communication, is to be coiled separately on the iron. The ends of all the wires must then be collected into two separate parcels, and made to communicate with the same voltaic battery, taking care that the current shall pass along each wire in the same direction. A powerful arrangement of this kind is now in my possession. It consists of a piece of very soft and pure iron, bent into a horse-shoe form, and weighing seventy-five pounds; between four and five hundred feet of covered copper wire are wound round it, in six or seven different strands, the wire on each strand increasing in thickness from the first: only the first two coils are wound round the bend of the iron, the remainder, after encircling two-thirds of one side, are passed over to the other. The whole of the projecting ends are soldered together, and fastened to two large brass balls, into which stout brass rods screw, for effecting the communication with the battery: the whole is covered with red leather, and suspended to a tripod formed of three stout poles twelve feet high; the armature consists of a piece of similar iron, weighing twelve pounds, the surface of which is planed perfectly smooth and even, as are also the poles of the magnet. A stout hook is fixed in the centre of the armature, from which a large scale is suspended. The iron is excited by dipping the brass rods into the mercury cups of the battery shown in *Fig.* 20, highly charged with a mixture of two parts of nitric, four sulphuric, and two hundred and fifty water. The moment the communication is established, the apparatus becomes powerfully magnetic, and if the armature be held in the hand about half an inch under the poles, at the moment the rods are dipped into the cups, it will be drawn up with surprising and resistless force, and will sustain a weight of ten or twelve hundred weight. If the rods are removed from the mercury cups, while the armature is still attached to the magnet, it will nevertheless remain fixed with considerable force, although no electricity is passing; but after it has been once removed, it will not be attracted again, nor will the magnet support even a large nail. If the brass rods are grasped in the hands moistened with salt and water, and one placed permanently in its mercury cup, while the other is dipped in and out of its cup rapidly, a distinct, though feeble shock will be felt in the wrist, every time the contact with the mercury is broken.

But the most extraordinary sensation is experienced when the poles of the magnet are quickly reversed, by changing the direction of the electric current, which may easily be done by employing Clarke's electrepeter. The armature must be held about an inch and a half or two inches under the poles; at first, a powerful attraction is felt, then for a moment it ceases, then is instantaneously renewed, and the hand is drawn up as before; the same is repeated as often as the direction of the current is changed. The time at which no attraction takes place, being of course, when the arms c c of the electrepeter are in a horizontal position.*

The Rev. N. J. Callan, Professor of Natural Philosophy in the Roman Catholic College, Maynooth, has described in Sturgeon's Annals of Electricity, &c., for July, 1837, an electro-magnet, which appears to be by far the most powerful instrument ever before constructed. The iron bar of which it is composed weighs fifteen stone, it is two and a half inches in diameter, and more than thirteen feet in length, it is bent into the form of a horse-shoe, and the distance between the poles is seven inches. A copper wire one-sixth of an inch in diameter, is coiled once round the whole length of the iron bar. This wire is divided into seven parts, each about seventy feet long. A thin copper wire about one-fortieth of an inch in diameter, is soldered to one of the thick wires at about a foot from one of its extremities. The thin wire is about ten thousand feet long, it is wound round the magnet in the same direction as the thick wire, and in one continuous coil. By connecting the opposite ends of the seven thick wires, with the opposite poles of a powerful galvanic battery, an extraordinary magnetic power is communicated to the iron bar; and by breaking the battery communication, an electric current of enormous intensity is excited in the long coil of thin wire. (See next Lecture.)

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* In experiments of this sort, where the poles of the magnet are often reversed, it is necessary to observe the precaution of providing ropes for the armature, that it should not fall to the ground, by which serious mischief might be occasioned. A stout rope passed two or three times through the ring by which the scale is attached, and the ring at top from which the magnet is suspended, will be all that is required.

When the above communication was made, Mr. Callan had tried the magnetic and electric powers of this magnet only once; he first used a large battery of twenty pairs of plates, each two feet square, and afterwards a Wollaston battery, containing two hundred and eighty pairs of four-inch plates. When the opposite extremities of the seven thick wires were connected with the opposite ends of the battery of large plates, it was found impossible to separate the keeper from the magnet, by any force acting in a direction opposite to that in which the magnetic force was exerted. The keeper was a horse-shoe bar of iron about twenty inches long, and two and a half inches in diameter. The highest point of the arc formed by the keeper was seven inches, and the distance between its poles was the same as the distance between the poles of the magnet; it weighed twenty-eight pounds. Mr. Callan found that the magnetic power communicated by the twenty large plates, was considerably greater than that communicated by two hundred and eighty small pairs. The reason of this will be understood by referring to the fourth Lecture, where the distinction between simple and compound voltaic circles is pointed out. To produce the greatest effect on iron, it is requisite to set a very large *quantity* of electricity in motion round it, without any or but little regard to what is called the *intensity* of that current, and this object is acccomplished, by employing a few voltaic pairs of a large size. The calorimotor shown in *Fig.* 20, which consists of only a single pair of plates, presenting a surface of eighteen square feet of copper, and sixteen of zinc, I find much more efficacious in exciting my large magnet, than my Wollaston battery of one hundred double pairs highly excited. It may be as well also to state here that by the application of the principle of electro-dynamics, we are now enabled to obtain from a single pair, a succession of shocks far more intense and insupportable than any that can be given by an extended series on the most improved construction. In the next Lecture this will be fully described.

The electric power of Professor Callan's magnet, was shown not only by the brilliant combustion of charcoal, but also by the *destruction of animal life.* As often as the connexion between charcoal points attached to the thick wires and the battery was broken, the succession of sparks was so rapid, that they formed a continued blaze of vivid light; and when by means of an electro-magnetic repeater, (see next Lecture,) a rapid succession of the currents excited in the long coil, was passed through the body of a large fowl, instant death was produced.

One of the first enquiries that the discovery of this wonderful property of iron to become powerfully magnetic by the action of current electricity, gave rise to, was—can it not be applied as a moving power? The person who appears to have first answered this important question, and who was strictly the inventor of a method of applying galvanism to produce rotatory motion, was Mr. Thomas Davenport, of Brandon, in the county of Rutland, and state of Vermont. To this individual more than ordinary merit is due, since it appears that he was without the advantages of education, and unaided by scientific knowledge, by books, or by the encouragement of men of superior attainments. He is by trade a blacksmith. By accident he saw one of Professor Henry's electro-magnets, which he immediately purchased, with a conviction that he could render it available as a motive power; this was in 1833, and, in July, 1834, he had so far succeeded as to produce a rotative engine.

In Silliman's journal for April, 1837, there is a notice of this machine, for which a patent was granted in the February previous. I must refer you to that periodical, and to the "Journal of the Franklin Institute," for a full description, as my limits will not allow of more than a general outline.

"The moving part is composed of two iron bars placed horizontally and crossing each other at right angles; they are covered with insulated copper wire, and sustained by a vertical axis; connection with a small voltaic battery is made in the usual manner. Two semicircles of strongly magnetised steel form an entire circle, interrupted only at the two opposite poles; and within this circle, which lies horizontally, the galvanized iron cross moves, in such a manner that its iron segments revolve parallel, and very near to the magnetic circle, and in the same plane. Its axis at its upper end, is fitted by a horizontal cog wheel, to another and larger vertical wheel, to whose horizontal axis weight is attached and raised by the winding of a rope. By the galvanic connection these crosses and their connected segments, are magnetised, acquiring north and south polarity at their opposite ends, and being thus subjected to the attracting and repelling force of the circular fixed magnets, a rapid horizontal movement is produced, at the rate of six hundred revolutions in a minute, when a large calorimotor is employed. The movement is instantly stopped by breaking the connection with the battery, and then reversed by simply interchanging the connection of the wires of the battery with those of the machine, when it becomes equally rapid in the opposite direction."

Galvanometers.—This instrument, the simplest form of which is shown in *Fig.* 92, was originally suggested by Professor Schweigger of Halle, very soon after the discovery of electro-magnetism, and was by him called an *electro-magnetic multiplier*. The effect of passing an electric current through the wire, in the direction pointed out by the arrows, *Fig.* 92, is, as we have seen, to deflect the needle from its natural position, and to bring it into a position nearer to a right angle to the plane of the wire. To multiply this effect, and to render the instrument a more susceptible indicator of feeble electrical currents, various forms have been given to the instrument; in all, the convolutions of the wire are multiplied, and the lateral transfer of electricity prevented by coating it with sealing-wax or

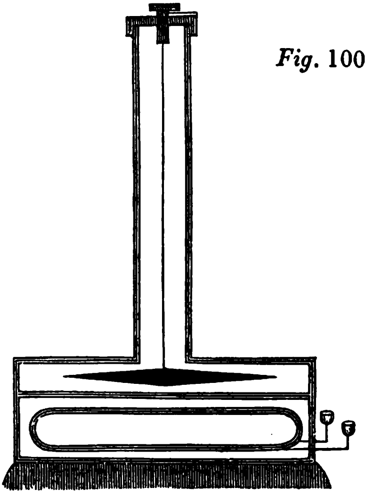


Fig. 100.

silk. *Fig.* 100 is a vertical section of the torsion galvanometer of the late Professor Ritchie. The following is his description of its construction :— " Take a fine copper wire, and cover it with a thin coating of sealing wax, roll it about a heated cylinder, an inch or two in diameter, ten, twenty, and any number of times, according to the delicacy of the instrument required. Press together the opposite sides of the circular coil till they become parallel, and about an inch, or an inch and a half long. Fix the coil in a proper sole, and connect the ends of the wires with two small metallic cups, for holding each a drop of mercury. Paste a circular slip of paper, divided into equal parts horizontally, on the upper half of the coil, and having a black line drawn through its centre, and in the same direction with the middle of the coil.

Fix a small magnet, made of a common sewing needle, or piece of steel wire, to the lower end of a fine glass thread, while the upper end is securely fixed with sealing-wax in the centre of a moveable index, as in the common torsion balance. The glass thread should be inclosed in a tube of glass, which fits into a disc of thick plate glass, covering the upper side of the wooden box containing the coil and magnetic needle."—*Philosophical Transactions for* 1830, *p.* 218.

The sensibility of this instrument is very much increased by neutralizing the magnetic influence of the earth, by employing two needles, which was first done by Professor Cumming of Cambridge, and afterwards on an improved principle by Nobili. The neutralizing needle in his instrument is attached to the principal one; placing them one above another and parallel to each other, but with their poles in opposite directions. They are fixed by being passed through a straw, suspended from a thread. The distance between the needles is such as to allow of the upper coil of the wires to pass between them, an opening being purposely left, by the separation of the wires at the middle of that coil, for allowing the middle of the straw to pass freely through it. A graduated circle, on which the deviation of the needle is measured, is placed over the wire, on the upper surface of the frame of the instrument, having an aperture in its centre, for the free passage of the needle and straw. The whole of this arrangement will be easily understood, by imagining another needle to be suspended to the one above the coil in *Fig.* 100, moving *within* the wire, and having its poles turned the reverse of those of the upper needle. In Nobili's instrument, the frame was twenty two lines long, twelve wide, and six high. The wire was of copper, covered with silk, one-fifth of a line in diameter, and from twenty-nine to thirty feet in length, making seventy-two revolutions round the frame. The needles were twenty-two lines long, three lines wide, a quarter of a line thick, and they were placed on the straw five lines apart from each other.—*Roget's Treatise.*

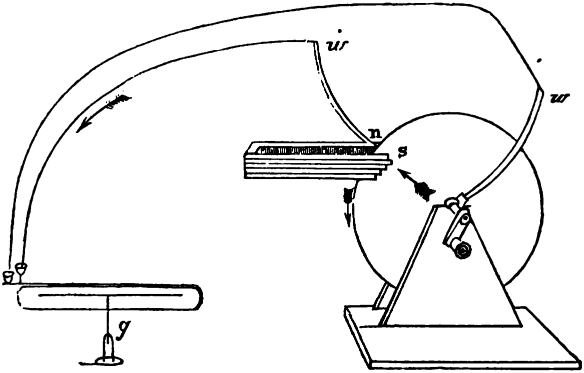
The advantages of Nobili's instrument, consist in the directive force, arising from the influence of the earth's magnetism being nearly balanced, and a double rotatory tendency being given to the needles. The lower needle is acted upon by the sum of the forces of the currents in every part of the coil, and the upper needle is acted upon by the excess of force in the upper current which is nearest to it, which force of course acts in a direction the reverse of that in which it acts upon the lower needle, being situated on the opposite side; but since the poles are also in a reversed position, the rotatory tendency becomes the same in both needles. M. Lebailiff has extended the principle of Nobili's galvanometer, by employing four needles, two within the coil, having their poles similarly situated, and one above, and one below, having their poles reversed. He likewise employs five parallel wires, each sixty feet long for the coil, instead of one length of three hundred feet; by this means, the current is divided into five parts, and made to flow through five different channels, with the alleged advantage of increasing the quantity, and diminishing the intensity of the electricity; it is not decided whether this is the case, nor is the advantage of employing four needles sufficiently obvious.

LECTURE VIII.

ON MAGNETO-ELECTRICITY.

FROM the facts stated in the last lecture, the inference that magnetism is in some way produced by electricity in motion, may be readily drawn; and it was in consequence of certain phenomena observed by Dr. Faraday, relating to the development of electricity by the vicinity of an excited body, that he was led to inquire, whether magnetism in motion ought not to produce an electric current; and he at length succeeded in establishing this interesting fact by the following means: he took a long insulated copper wire, and formed it into a helix; the ends were then connected with a galvanometer, the deflection of which would of course indicate a current of electricity. He now found that in the act of introducing the pole of a powerful bar magnet within the coil, a deflection of the galvanometer took place in one direction, and that in the act of withdrawing it, a deflection took place in an opposite direction; so that each time the conducting wire cut the magnetic curves, a current of electricity was for the moment produced in it. This experiment was afterwards varied, by employing the apparatus shown in *Fig*. 101. It consists of a copper plate mounted

Fig. 101.



on an axis, and furnished with a handle for giving it motion; *w w*, are conducting wires; the one retained in perfect metallic contact with the axis, and the other with the circumference of the disc; a powerful horse-shoe magnet is then so placed as to allow of the revolution of the disc between its poles, and the wires, *w w*, are connected with the galvanometer, *g;* the wire, *w*, is retained on the circumference of the disc, at the point between the poles of the magnet. When this machine is made to revolve from right to left, a current of electricity from the centre to the circumference is determined in the direction of the arrows, and the galvanometer is deflected accordingly. If the revolution of the disc, or the poles of the magnet be reversed, the electric current moves in an opposite direction.

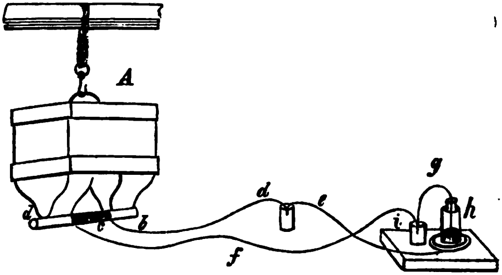
The same experimentalist has also succeeded in laying open a new branch of electro-dynamics, by proving that electricity in motion may be excited by induction. He took a copper wire two hundred and three feet long, and wound it round a large block of wood in the form of a helix, and an equal length of similar wire in the same direction, so that the coils of each helix were interposed, but without contact, between the coils of the other. The ends of one of the helices were connected with a galvanometer, and the other with a strong galvanic battery, with a view of ascertaining whether the passage of the electrical current through one helix, would not induce a current on the other. It was found that the galvanometer indicated a current, at the moment both of completing and breaking the circuit, but that *in the interval, no deflection took place;* and similarly, the *induced* currents *readily magnetised a sewing needle* while the electric current along the inducing helix was in the act of beginning or ceasing to flow, but at no other time. By varying the experiment, a similar result was obtained, it being only at the time of breaking or making the voltaic circuit, that an electric current is induced on one helix, by the current transmitted through an adjoining one. In the former case, the direction of the induced current is opposite to that of the inducing current, and in the latter case it is the same. This phenomenon is distinguished by Dr. Faraday, by the name of *volta-electric induction.*

If a ring of soft iron be covered to nearly half its extent by several helices of insulated copper wire, and the ends brought together, so as to form a compound helix, and the other half of the ring arranged with similar helices, the two sets being separated and protected by cloth, from direct contact with the iron; on making a communication with a voltaic battery by means of the terminal wires of one helix, and with a galvanometer through the terminal wires of the other, a strong deflection of the needle takes place at the moment of contact. The action is not however so powerful, as when a cylinder of soft iron is introduced into a pasteboard case, round which are wound two compound helices of copper wire. This, which belongs to the same class of phenomena as the experiments first described, is called magneto-electric induction.

The phenomena arising from *volta-electric* and *magneto-electric* induction, depend on the same condition of the induced wire, and the action on the needle is identical; in both, the agent is an electric current, and that current is in the same electric state as the conducting wire in a closed voltaic circle. When the phenomena are exhibited by inserting a piece of soft iron into a pasteboard case, round which a current of electricity is made to circulate; the induced current is called forth by the temporary magnetism induced on the iron; and this is further proved by converting the soft iron into a temporary magnet, not by an electric current, but by placing at each of its ends, the opposite pole of a powerful permanent steel magnet, the action on the galvanometer is exhibited during the act of applying the magnetic poles to the iron, and in an opposite direction on their removal.

By connecting a frog's leg with the induced wire, Faraday was the first who succeeded in throwing it into spasms, and by arming the ends of that wire with points of charcoal, and separating them at the instant the galvanic circle was broken or restored, sparks of electricity were obtained. After this experiment was announced, various attempts were made to effect the same with a permanent steel magnet or loadstone, without the intervention of galvanism; and the first person who succeeded in this country, was Forbes, who operated with the natural magnet presented to the University of Edinburgh, by Dr. Hope, and capable of supporting one hundred and seventy pounds. The arrangement of the apparatus, with which Mr. Forbes succeeded in obtaining the spark on the 13th of April, 1832, is shown in *Fig*. 102. The large natural magnet is represented at A. A cylindrical connecter of soft iron, *a b*, passing through the axis of the helix, *c*, was made to connect the poles of the magnet; accuracy of contact was found to be of considerable importance to the success of the experiment, and one side of the cylinder was carefully formed to a curve, of about two inches radius, for this purpose. Great advantage was found from a mechanical guide, not represented in the figure, to enable an assistant to bring up the connecter rapidly and accurately, to a magnet, in the dark. The helix *c*, consisted of about one hundred and fifty feet of copper wire, nearly one-

Fig. 102.



twentieth of an inch in diameter, seven inches and a half long, and containing four layers in thickness, which were carefully separated by insulating partitions of cloth and sealing-wax. The one termination, *d e*, of the wire, passed into the bottom of a glass tube, *h*, half filled with mercury, in which the wire terminated, and the purity of the mercurial surface is of great consequence in the experiment. The other extremity, *f*, of the heliacal wire, communicated by means of the cup of mercury, *i*, with the iron wire, *g*, the fine point of which may be brought by the hand, into contact with the surface of the mercury, in *h*, and separated from it at the instant when the contact of the connecter, *a b*, with the poles of the magnet, is effected. The spark is produced in the tube, *h*.

Mr. Forbes was able with a little practice to produce for many times in succession, at least two sparks, which were generally of a fine green colour from every three successive contacts; the success of the experiment clearly depending on the synchronism of the production of the momentary current, by connecting the magnetic poles, and the interruption of the galvanic circuit at the surface of the mercury.

It was in the September of the same year, that M. Hypolíte Pixii of Paris, made public his magneto-electric machine, at the meeting of the Académie des Sciences; a description of this invention will be found in the Annales de Chimie for July, 1832, and a representation of it in Becquerel's Traite de l'Electricitié, vol. iii. A powerful magnet was made to revolve rapidly before its armature, which was furnished with a coil of copper wire, about three thousand feet in length, by which means sparks and strong shocks were obtained, a gold-leaf electrometer was made to diverge. a Leyden phial was weakly charged, and water was decomposed.

At the meeting of the British Association, at Cambridge, in June, 1833, Mr. Saxton exhibited his improvement on Pixii's machine. In this instrument the armature revolves instead of the magnet, and the interruptions are produced by the revolution of points, instead of bringing one of the ends of the wire over a cup of mercury, and depending on the jerks given to the instrument by its rotation, for making and breaking the contact with the mercury.

But the most useful and elegant machine is that arranged by Mr. E. M. Clarke, of the Lowther Arcade, a description of which I shall now insert.

Fig. 103* represents the battery of bent bar magnets, placed vertically, and resting against four adjusting screws, which pass through the mahogany back-board, B; C, is a bar of stout brass, having an opening in the middle, through which passes a bolt, with a screw wheel, the purpose of which is to draw the magnetic battery to the board B. By these means the battery can readily be disengaged from the machine, without taking asunder the entire apparatus, and the battery is thus also freed from that vibration which must necessarily be occasioned by the attachment of the rotating apparatus to the battery itself. D, is the intensity armature, or inductor, which screws into a brass mandrill, seated between the poles of the battery A; motion being communicated to it by the multiplying wheel E. This armature has two coils of fine insulated copper wire, one thousand five hundred yards long, coiled on its cylinders, the commencement of each coil being soldered to the armature D, from which projects a brass stem, (also soldered into D,) which carries the break pieces, H and H: the break piece is made fast in what position soever is required by a small binding screw. K and K, a hollow brass cylinder, to which the terminations of the coils, F G, are soldered, being insulated by a piece of hard wood, attached to the brass stem. O and O, are iron wire springs, pressing against the hollow cylinder, K, at one end, and held in metallic contact by a nurled head screw, in the brass strap, N, which is fixed to the side of the wooden block, L. P and P, a square brass pillar, fitting into a square opening in the other brass strap, N, and secured at any convenient height required. Q and Q, a metal spring, that rubs gently on the break piece, H, and held in perfect metallic contact by the nurled head screw in P. T and T, a piece of copper wire for connecting the two brass straps, M N; then D H Q P N, are in connection with the commencements of each coil, and K O M, with the terminations. The advantages of this arrangement are that mercury is not required, as in Saxton's machine, by which much loss and inconvenience is occasioned by its being scattered about by the disc and blades. By Clarke's arrangement, the metal spring Q, presses gently on the break H, consequently, the effects here are unbroken, no matter how long the machine may be required to be kept in action; this is not the only advantage it possesses, for in the mercury, the surface is very rapidly oxidated; the oxide adheres to both disc and point, and preventing so perfect a metallic contact as that obtained by the spring and break.

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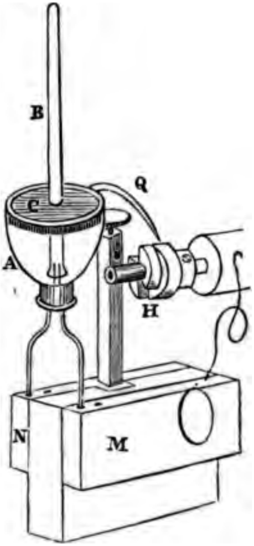
* See Frontispiece.

To adjust the intensity inductor, the faces of the iron cylinders, that carry the coils F G, must be placed parallel to, and nearly in contact with the battery, A; this can easily be done, and the battery adjusted with the greatest nicety, by means of the screws at the back of the machine; the break must then be so adjusted, that the spring Q, will separate from it, just at the same time that the iron cylinders of the inductor, have left the poles of the magnetic battery, and lastly, the iron wire spring O, must press gently against the hollow brass cylinder, H.

In order to give the shock, the two brass conductors R S, must be grasped in the hands, and one of their connecting wires put into the holes of either of the brass slips, M or N, and the other wire into the hole at the end of the brass stem, that carries the break H. M N must then be connected by T, and on turning the wheel, a violent shock will be felt by the person holding R S. When the wheel is rapidly turned, the quick succession of shocks is absolutely intolerable, and produces so violent an effect on the muscles of the arm, that they contract, and cause the hands to clench the conductors involuntarily, and the person is left at the mercy of the operator, it being quite impossible to let go: the better way of taking the shock, is therefore to plunge R S into two separate basins of salt and water, and immerse a hand in each. If the two connecting wires of R S are put in M N, the shock is not so powerful. The shock may be modified in different ways, by turning the wheel E, very slowly, or increasing the distance between the battery A, and the armature D; or, by making the break H, separate from the spring Q, when the armature D is horizontal. U V, represents a pair of directors, holding a piece of sponge, to be used when electricity is to be applied medicinally. The connecting wires are to be placed in the same way as the conductors are in the figure; the sponges must be wetted with a little vinegar, or salt and water, so as to make them conduct the electricity. By those directors, a succcession of most powerful shocks can be given, when the case requires it; or they can be so modified as to be barely felt by the most nervous patient.

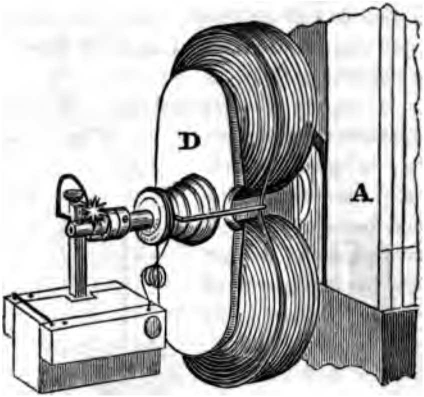
Water is readily decomposed by this instrument. *Fig.* 104, shows the arrangement A, a glass vessel, having a brass cup, with hard wood bottom, through which, two pieces of copper wire pass, having pieces of platina wire soldered to them; this is placed in M N, and the tube B filled with acidulated water, and placed as in the figure; Q must rub on the cylindrical part of the break H; here the gases are obtained mixed. In order to obtain the oxygen and hydrogen in a separate state, two tubes are employed, and the bent wire Q, made to work on the single break.

Fig. 104.



The quantity inductor, or armature, differs materially from that employed for intensity effects. The weight of iron, in the cylinders, is much greater, the length of copper wire, much less, being only forty yards, instead of one thousand five hundred, and the wire itself is much thicker. *Fig.* 105 represents the battery, armed with its quantity inductor, and the plan for exhibiting the spark; care is to be taken that the spring separate from the break, at the same time that the armature is vertical, being then in a neutral position as respects the poles of the battery.

Fig. 105.



With this inductor, all the effects depending on quantity are exhibited; it may be compared, therefore, to a calorimotor, or single pair of voltaic plates, while the other is analogous to the compound battery. It exhibits in a beautiful manner the scintillation of iron wire, it ignites platina wire, and renders soft iron magnetic. *Figures* 106 and 107 represent the manner in which the two latter effects are accomplished.

Fig. 106.

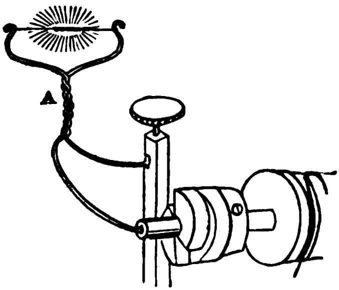


Fig. 107.

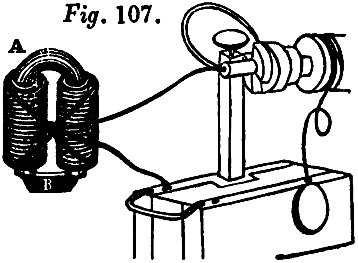
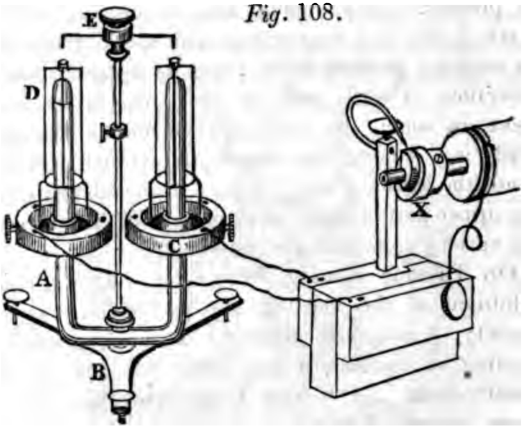


Fig. 108 shows the manner in which rotations may be produced by magnetic electricity. A, is a vertical horse-shoe magnet, on a tripod stand; B C, the mercury cups; D, the wire frames, having two little cups at the top to hold a drop of mercury; E, a connecting fork. Mercury being poured into the flood cups, C, and the single break, X, being used, on placing the connecting wires as in the figure, continuous rotatory motion will be produced by this arrangement, the currents being constantly in the same direction. But the experiment may be varied by substituting the double break, H, (*Fig.* 103,) the currents now alternating.

Fig. 108.



I have given this detailed description of Mr. Clarke's magnetic electrical machine, because it is *so very superior* to any other instrument of the kind previously before the public, and because I wish particularly to recommend it to the notice of all lovers of science. Mere description is quite inadequate to convey a just impression of the neatness and brilliancy of many of the experiments; the machine should be seen at work to be appreciated. Mr. Clarke has recently supplied me with an excellent instrument; and all to whom I have exhibited it, have readily acknowledged its superiority over every other form of the machine. The spark from the quantity inductor, as shown by the double break, is sufficiently intense to illuminate a moderate sized room, so as to enable a person distinctly to tell the hour and minute, on a watch at the further extremity; and when viewed through a micrometer eye-piece, gives a brilliant star, accompanied by prismatic rays; and it must be observed that this spark is the real magneto-electric spark, there being no mercury present to increase its apparent size by reflection, as is the case in other forms of the instrument, in which the spark appears double the size it really is. Among other merits, its extreme portability is not the least; it shuts up in a neat mahogany case, the upper part of which contains a small box, in which the various apparatus are contained.

On Tuesday evening, September 4th, Mr. Clarke exhibited at the meeting of the London Electrical Society, a magnetic electrical machine, greatly exceeding in dimensions any other that has yet been constructed; the battery being separated into two parts, connected together by the inductors rotating at their sides. The quantity arrangement being at one side, and the intensity on the other: the results with the machine in this form, were so opposite to what was anticipated, that Mr. Clarke first suspected his arrangement to be defective. As usual, the quantity inductor was furnished with a short coil of thick insulated copper wire, and the intensity inductor with 15,375 yards of fine copper wire. On trying the voltameter with the intensity arrangement, to his astonishment no decomposition took place, although the shock obtained by it was most excruciating, nay, even dangerous. Mr. Clarke next tried the decomposing power of the quantity inductor, and obtained one cubic inch of the mixed gases in four minutes. This being a novel fact, he was induced to imagine that the cause might be traced to a compound action, produced by the rotation of the two inductors, and he therefore determined to arrange the magnets similarly to those of the machines he had been in the habit of constructing; the only difference consisting in the size of the instrument, and in the means of communicating motion to the inductors; namely, by a crank and treadles, similar to a lathe. The battery consists of ten polished cut steel bars, each four feet long, the whole weighing one hundred and fifty-six pounds: ivory was made use of to retain the wires on the inductors, in lieu of brass plates, which gave uncertain results, owing to their conducting property. The novel results of the experiments, were first, the great amount of gas obtained by the quantity inductor,—in one instance, one cubic inch in one minute and a half, which result confirmed the correctness of the original arrangement. The second, was the trifling decomposing effect from the intensity inductor, as appeared from the table which Mr. Clarke exhibited. The voltameter employed in the experiments, was furnished with two slips of platina, one inch in length, and three-eights of an inch in breadth; the decomposing power was however increased at least fifteen times, by the substitution of fine pointed wires of platina. The next experiment referred to the different appearance of the spark, with various modifications of the inductors: with the intensity inductor a long, straggling, noiseless spark was obtained, having much resemblance to the spark which passes from the prime conductor of an electric machine to a body placed at what is called the striking distance. The quantity inductor gives a spark, which not only had the usual stellar form, but was accompanied by a loud snapping noise, resembling the discharge of a Leyden jar, although these distinctions existed between the sparks, they both appeared equally luminous. The experiments were most brilliant, and the results extremely important; they show the value of experiments on a large scale, for sifting out the intricacies of science, and extending the boundaries of knowledge; they show from the unexpected nature of the phenomena relating to decomposition, which they developed, how widely erroneous any conclusions drawn from microscopic observations must inevitably be; and how imperfect our present knowledge of the mighty agent of electricity is.

By employing a secondary coil I have given shocks with the quantity inductor almost as powerful as those obtained from the intensity inductor; but before I describe the method, I must direct your attention more particularly to that curious branch of the subject of electro-dynamics, relating to secondary electrical effects, by induction.

If a small pair of voltaic plates be moderately excited, and a small short wire used to connect its mercury cups, (see *Fig.* 19, page 103,) no spark or only a very minute one will be perceived, either on making or breaking contact. As however the length of the connecting wire increases, the spark becomes proportionally brighter, "*until, from extreme length, the resistance offered by the metal as a conductor, begins to interfere with the principal result;*"—these are the words of Dr. Faraday. If two equal lengths of wire be taken, and one made up into a helix, and the other laid out on the floor, and each used to connect the mercury cups of a small battery, very great difference will be observed in the size of the spark afforded by each, on breaking contact. Supposing the length of each to be sixty feet, the wire laid on the floor will give a small bright spark, while the wire wound into a helix, will produce a large brilliant spark accompanied by a snap. Again, to render the fact still more decisive, take one hundred feet of covered wire, and bend it in the middle, so as to form a double termination, which can be communicated with the electrometer; wind one half into a helix, and let the other remain in its extended condition; use these alternately as the connecting wire, and the helix will be found to give by far the strongest spark.

The spark and snap are much increased when a bar of soft iron, or what is better a bundle of iron wires, are introduced into the axis of the helix; but it is only on breaking contact with the battery that the effect is produced; the reason is, that the iron magnetised by the power of the continuing current, loses its magnetism at the moment the current ceases to pass, and in so doing tends to produce an electric current in the wire round it.

These effects are evidently dependent on some affections of the current in the conducting wire, and the spark produced when the cups of the electrometer are connected by a *short* wire, is the only one that can be considered as produced by the direct power of the battery; that the increase of the spark when the wire is lengthened does not depend on any thing analogous to *momentum*, in the electricity circulating through it, and consequently producing effects at the instant the current is stopped, is proved by the fact that the same length of wire produces the effects in very different degrees, according as it is simply extended or made into a helix, or forms the circuit of an electro-magnet. How then is it to be accounted for? The ingenuity of *Dr.* Faraday has provided an answer.

In his ninth series of experimental researches, he has shown, that if a current be established in a wire, and another wire forming a complete circuit be placed parallel to the first, at the moment the current in the first is stopped, it induces a current in the same direction in the second, the first exhibiting then but a feeble spark; but if the second wire be away, disjunction of the first wire, induces a current in itself in the same direction, producing a strong spark.

The strong spark in the single long wire, or helix, at the moment of disjunction, is, therefore the equivalent of the current which would be produced in a neighbouring wire, if such second current were permitted. Viewing the phenomena, therefore, as the results of the induction of electrical currents, the different effects of short wires, long wires, helices, and electro-magnets, may be comprehended. If the inductive action of a wire a foot long, upon a collateral wire, also a foot in length, be observed, it will be found very small; but if the same current be sent through a wire fifty feet long, it will induce in a neighbouring wire of fifty feet a far more powerful current, at the moment of making or breaking contact, each successive foot of wire adding to the sum of action: and by a parity of reasoning a similar effect should take place when the conducting wire is also that in which the induced current is formed: hence the reason why a long wire gives a brighter spark on breaking contact, than a short one, although it carries much less electricity.

If the long wire be made into a helix, it will then be still more effective in producing sparks and shocks, on breaking contact; for by the mutual inductive action of the convolutions, each aids its neighbour, and will be aided in turn, and the sum of effect will be greatly increased.

On repeating the beautiful experiments of Faraday, which led him to the above conclusion, I was induced to try the effects of strong and weak electrical currents, on a long flat coil, of considerable breadth of surface. For this purpose, I took two sheets of thin copper, each four feet and a half long, and twenty-six inches wide, and cutting them into ribbons, one inch wide, I soldered all the lengths together, and formed the whole into a single coil, with list intervening. I thus had a continuous coil of copper ribbon, two hundred and thirty-four feet long. At the commencement of the coil, and at intervals of twenty-five feet through its whole length, wires were soldered, which projected about two inches, and supported small cups to contain mercury. By this arrangement, I could send the current through what length of ribbon I pleased, from two hundred and thirty four to twenty-five feet, and by the aid of the mercury cups, I could examine the effect produced on one part of the wire, by the action of an electrical current sent through any other part. In describing some of the experiments made with this coil, which seem to bear on the present subject, I shall distinguish the cups, by figures, indicating their position on the coil, thus :—

1. 2. 3. 4. 5. 6. 7. 8. 9. 10.
corresponding to 25. 50. 75. 100. 125. 150. 175. 200. 234. feet.

1. When communication was made with the positive end of a pair of plates, contained in a pint cup, and excited by dilute sulphuric acid, and cup 1, and the wire from the negative end, dipped in succession

into 2. 3. &c., to the end of the arrangement, the spark and snap increased in intensity to 4.; at 5. it appeared the same, and afterwards went on decreasing to 10., where the spark was not nearly so large, nor was the snap nearly so loud: the maximum effect, therefore, seems to be produced with the battery, when the current has traversed between 75 and 100 feet.

2. When a half pint battery was employed, no difference in the size of the spark could be perceived in 4. 5. 6. 7. 8., but it was larger and brighter in these cups than in 2. 3., and 9. and 10., in which it seemed about the same: with a pair of plates, containing about one-fourth the surface of metal, no difference in the size, or appearance of the spark, could be perceived throughout the whole arrangement, after cup 2., being as bright at 10. as at 3.

3. When a pair of plates, each two inches square, was employed, the spark seemed brighter at 9. and 10. than either at 4. 5. or 6.; with a pair one-inch square, the difference was more marked; with a pair half an inch square, it was feeble in 2. 3. 4., after which it went on increasing, and at 10. it was much larger; with a pair a quarter of an inch, I several times heard a slight snap, accompanying the spark in the last three cups; but the sparks produced in the first six cups, were decidedly smaller, and less bright.

4. A pair one eighth of an inch square, was then tried, sparks were produced in all the cups; feeble in 2. and 3., but in 7. 8. 9. 10. bright; largest and brightest in 10.

5. Strips of copper and zinc, half an inch long, and one tenth of an inch wide, were immersed in the

acidulated liquor, and connected with the coil, sparks were obtained in all the cups, bright in 8. 9. 10.; the strips were then cut in half, and by rapidly breaking contact, sparks were obtained in 5. 6. 7. 8. 9. 10., I could only occasionally get them from 4., and not at all from 2. and 3. The strips were then reduced to about one-sixth of an inch long, and one-twentieth wide; in 9. and 10. I obtained several sparks, but could get none from any of the other cups.

6. The large calorimotor *(Fig.* 20*)* recently cleaned and highly excited with nitrous acid, was then tried; the brightest and loudest spark was at 2.; the snap was very loud, and could be distinctly heard in a room, at the bottom of a flight of stairs, the door being shut, and also the door of the room in which the experiments were made; it was as loud, every time contact was broken, as the explosion from a quart Leyden phial; the sparks were very vivid, and evolved copious fumes of mercury: these effects rapidly diminished as the connecting wire approached the termination of the coil, and at 8. 9. 10., the sparks were not more brilliant, nor louder, than those produced by the half-pint battery.

7. The shock with this apparatus, did not increase with the spark: when one of the brass conductors, R S, (see Clarke's machine) was grasped by the hand, and kept permanently in 1., and the other held in the left hand, and dipped successively into each of the other cups, in which contact with the battery, was rapidly broken by an assistant, the large calorimotor being employed, the following were the results:—

8. The left hand conductor being in cup 2., and contact with the battery broken in it, the shock was

very slight, in 3. it was stronger, and went on increasing to 10., where it was strong enough to be felt at the elbows; now the spark and snap were most intense in 2., and least in 10.; hence the shock appears to be inversely as the spark.

9. The left hand conductor was then dipped into the cup, *next* to that in which contact was broken, being out of the circuit of the current, as for instance, in 3., while contact was broken in 2., the shock went on increasing, as before, to the end of the arrangement, it was then kept permanently in 6., while contact was broken in all the other cups; in 2. 3. 4. the shocks were distinctly felt, and went on increasing to 9.

10. The current was then passed from 2. to 9., while the conductors were held in 1. and 10., then from 3. to 8., then from 4. to 7., then from 5. to 6., shocks were felt in all cases, strongest when the current was from 2. to 9., and weakest when from 5. to 6.

11. The wires from the battery were then connected with 1. and 2., and the conductors held in 3. and 4., then in 1. and 3., while the conductors were in 4. and 5., 1. and 4., 5. and 6., &c., but no shocks were felt, even when the wires from the battery, were in 1. and 8., and the conductors held in 9. and 10.

12. Although however no shock could be obtained *directly* from this arrangement, yet the existence of a secondary current was easily proved by the galvanometer, when the positive wire from the battery was in 1., and contact broken by the negative wire in 2., one wire of the galvanometer being in 3., and the other in 10., the needle was strongly deflected in a

direction indicating the passage of a current in the same direction as the inducing current, that is, from 3. to 10. When the needle had taken up its position, it was retained in it by a pin, contact was then broken in 2., and the needle was immediately deflected in a contrary direction, showing now the passage of a current from 10. to 3.

13. By employing Callan's coil, (an arrangement to be described presently), powerful shocks were obtained from the secondary current; the wires from the large calorimotor being in 1. and 2., and the terminal wires of the primary coil in 3. and 10., shocks felt at the elbows, occurred every time contact was broken, and when this was done rapidly by a revolving wheel, *(Fig. 90)*, or by Ritchie's rotating magnet, the succession of shocks was almost intolerable, and when one of the wires of the primary coil, was dipped in the same cup in which contact with the battery was broken, the shocks were very violent, even with a half-pint battery. When a wheel was employed to break contact, the scintillations were very brilliant, when it was connected with the first four cups of the coil. The well known optical illusion, of a body in rapid motion appearing stationary, was beautifully shown when the room was darkened, and the large battery used. Without the intervention of Callan's coil, the shocks obtained by breaking contact, by means of the wheel in the arrangement (8.), were not so strong as was expected; the most efficient method in this case was to draw the end of the connecting wire, rapidly over the edges of the ribbon, from the centre to the circumference.

14. I obtained secondary shocks from the coil im-

mediately; i. e., without the intervention of Callan's apparatus, by dipping the conductors grasped by the hand, in 10., and the negative cup of the battery, while contact was broken in 2. 3. 4. 5. 6. 7. 8. and 9.; in the last three the shocks were as strong as could be given with any other arrangement of the apparatus, and when Callan's coil was interposed, very severe, even when contact was broken by 2., and a half pint battery employed.

15. The wire from the zinc end of the battery was then kept permanently in 10., and contact with the copper end broken in 9. 8. 7. 6. 5. 4. 3. and 2., the left hand conductor being in 1., and the right in the positive cup. Shocks were felt in all; slight in 9. and 8., and strong in 4. 3. 2.*

All these experiments relative to the shock, are readily explained on the principles of volta-induction, developed by Faraday; but it does not seem quite so easy to understand the reason of the different appearances of the spark, with large and small voltaic pairs, in the different cups of the coil. In some experiments with a similar apparatus, described in the fourth number of Sturgeon's Annals of Electricity, by Dr. Page, a length of seventy-five feet is described as producing the maximum spark, every few feet less or more diminishing the effect; but Dr. Page must have experimented with only one battery, or he could not fail to have observed that there *is* a great difference in the size and appearance of the spark, in the different cups, with batteries varying in size. Thus with a pair of plates each seventeen feet square, highly charged with nitrous acid, I found that the brightest, largest, and loudest sparks were produced in the 2nd cup through an interval of twenty-five feet, and that they rapidly diminished in intensity as the length through which the current passed increased, till at the 10th cup, through two hundred and thirty-four feet, they were not greater than a small battery in a half-pint cup produced: on the other hand, when the voltaic pair was very small, increasing the length of the spiral conductor evidently increased the size of the spark, and I found also by using batteries of various sizes, that with a certain surface of copper and zinc, the spark would appear the same throughout the whole arrangement, and that this size was at or about twenty-four square inches, (both surfaces) of each metal.

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* After these experiments were made, the ribbon was cut down the middle, and soldered together so as to form a length of about four hundred and sixty feet, half an inch wide, which was insulated, and wound as before, into a spiral: the maximum spark, with this arrangement, a pint battery being used, was at about one hundred and fifty feet; and with a very small voltaic pair, the largest and brightest spark was still at the extremity of the spiral; on the whole, the effect of dividing the copper ribbon, was to

Whether, if instead of employing a coil, an equal length of copper ribbon laid out on the floor, would give a larger spark, at the extremity than at the commencement, with a small pair, I did not think of trying; if not, the increase of effect with the coil is evidently due to the mutual inductive action of its convolutions, but at the same time, the same inductive action takes place when a large battery is employed, and yet, as we have seen, it does *not* increase the sum of effect.

diminish the *size* of the spark, but greatly to increase the intensity of the shock, which, when obtained from the last cup, and the negative end of the battery, was very severe. Water was readily decomposed by the secondary current, developed by this arrangement.

If, as Faraday has stated, great length of metal offers resistance, as a conductor, to the current electricity, we should expect that with a voltaic pair, consisting of two wires a quarter of an inch long, the resistance which the small current would meet with in traversing two hundred and thirty-four feet of copper ribbon, an inch wide, would be sufficient to stop it altogether; but the fact of its being increased by such a passage in the coil, gives additional probability to the operation of inductive action :—the difficulty is in understanding why it should increase the effect with a very small pair, but diminish it with a large pair; this is not, however, the place for discussing the subject, it is my business rather to occupy myself with describing what has been done by experimentalists, towards the general elucidation of this very interesting subject of electro-dynamics. I proceed therefore with a description of an arrangement for producing powerful shocks, and strong electrolytic action, by *secondary currents* alone. An apparatus of this sort, was first made by Professor Callan, of Maynooth. The form of coil and contact breaker, here described, was devised by Mr. Golding Bird, Lecturer of experimental philosophy, at Guy's Hospital, and constructed for me, by Mr. Neeves, of Great St. Andrew's Street, Holborn. *Fig.* 109, represents the contact breaker, and shows the manner in which it is connected with the coil. *Fig.* 110, shows the whole arrangement at work, with the battery and magnets.

The contact breaker is thus constructed. A base board, about eight inches in length, and three in breadth, is furnished at both ends with a piece of hard wood, A and B, each having two holes excavated, for the purpose of holding mercury; each of these holes communicates by means of thick copper wires, D D′, with that opposed to it, in the other piece of wood at the opposite end of the board. Midway,

Fig. 109.

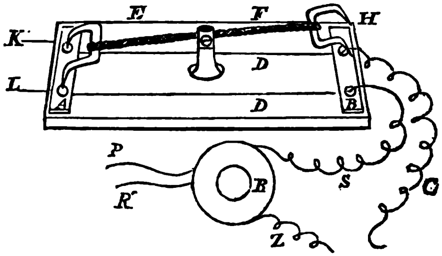
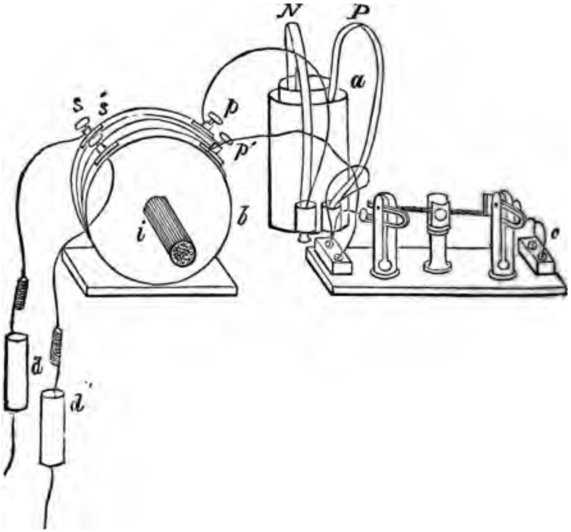


Fig. 110.



between the receptacles for mercury, is a wooden support, so contrived, that a piece of soft iron wire, one-eighth of an inch in diameter, and five inches in length, may oscillate between the cheeks cut in its upper part, with as little friction as possible, the iron wire being supported by milled-headed screws. Around this iron wire, E F, are wound two helices of thin insulated copper wire, in the same direction, (from right to left), in such a manner, that the two ends of one helix, may terminate in the copper points, G H, and the ends of the other helix, in the points, K L. Two small horse-shoe magnets, (not shown in *Fig.* 109, but represented in their proper places, in *Fig.* 110), are then fixed on proper supports, so that they may each be placed near an end of the iron bar, E F, in a vertical plane just posterior to it, so that on depressing the end F of the bar, it may be opposite one pole, (say the south) of one magnet, and consequently the end E will be opposite the other pole, of the second magnet. On elevating the end E, the contrary will of course take place, and for this purpose, it is hardly necessary to say, that the similar poles of the magnets should be in the same direction.

From this description, it is evident that on connecting the cup of mercury in A or B, with the two plates of a single voltaic battery, the bar E F will become a temporary magnet, if the ends of either helix are allowed to dip in the mercury: and if connection with the battery be properly made, the ends or poles of the temporary magnet, will be repelled by the poles of the permanent magnet, to which they are opposed; the bar will consequently move, and so cause the immersion of the ends of the second helix in the other cups of mercury; repulsion will again occur, and so on; about three hundred oscillations of the iron bar can thus be obtained in a minute.

The coil is thus arranged. On a reel, with a hollow axis, three inches in length, are wound about sixty feet of copper wire, one-twelfth of an inch in diameter, covered with cotton thread, for the purpose of insulation, the two ends being connected with *p p*, *(Fig.* 110*)* so that by means of the binding screws, communication may be made, by wires, with the contact breaker and battery; this is the primary coil; over it, a second insulated copper wire, one-eightieth of an inch in diameter, and about one thousand five hundred feet in length, is wound, and the two ends are connected with *s s*, furnished with binding screws, for forming connection with wires, for communicating the shock, &c.

The connection with the battery, is best made in the manner shown in *(Fig.* 109*)*, in which R represents a section of the reel, S one end of the short helix, connected with the mercury cup in B, *z* the other end of the short helix, connected with one plate of the battery, whilst the wire C connects the other cup of mercury, in B, with the other plate of the voltaic couple. When this is properly arranged, a series of induced currents may be obtained from *s s*, the extremities of the long helix, capable not only of communicating a series of intense shocks, but of exerting powerful electrolytic action; and when a bundle of soft iron wires is inserted in the hollow axis of the reel *i*, *(Fig.* 110*)*, the dynamic power of the coil, is considerably increased. In this case, indeed, the sparks produced, when the ends of the helices round the iron bar E F leave the mercury, are very brilliant, accompanied by a loud snapping noise and a vivid combustion of mercury, clouds of the oxide of that metal being copiously evolved.

If the ends P R′, of the long and thin coil, are furnished with platina points, and immersed in water, acidulated with sulphuric acid, rapid electrolytic action ensues, torrents of minute bubbles of oxygen and hydrogen gases, being evolved. If instead of water, the points are pressed on paper, moistened with iodide of potassium, electrolytic action ensues, iodine and oxide of potassium being separated. Solutions of neutral salts, such as sulphate of potash and soda, chloride of potassium, sodium, antimony, and copper, are also rapidly decomposed. In these experiments, as Mr. Bird remarks, it will be found that the great majority of the electro-positive elements (for example) appear constantly at one termination of the coil, *cæteris paribus*, but not all, for it must not be forgotten, that on making as well as breaking contact, with the electrometer, (see my experiments with the ribbon coil, par. 12), an induced current takes place in the long coil, though of far weaker intensity than the latter, to which it is opposed in direction, and consequently in electrolytic effects.

If the brass conducting tubes *d d′ (Fig.* 110*)*, are grasped, even with the unmoistened hands, the intensity of the rapid succession of shocks, will be found absolutely intolerable, even when the battery used, consists but of two plates, presenting four or five square inches of surface; and with pairs half an inch, the shocks obtained, when contact is rapidly broken, (which in this case, is best done by a rotating magnet, motion being communicated by the fingers), are very disagreeable.

When the wires, at the end of the conducting tubes *d d'*, are made to touch, small bright sparks are produced; and if while the oscillating bar of the contact breaker, is vibrating rapidly, a large calorimotor being employed, a piece of well burnt charcoal is fixed on one of the terminations, and the other drawn lightly over it, a rapid succession of brilliant sparks are obtained. These sparks depend entirely upon the induced currents, as the fine coil has no connection with the calorimotor. For the exhibition of this, as well as of the electric light of an energetic arrangement, Mr. Bird finds pencils of that kind of artificial graphite, found lining the interior of the iron cylinders, used for the distillation of coal in gas manufactories, very far superior to box-wood, or indeed any other form of charcoal.—(London and Edinburgh Philosophical Magazine, vol. xii. page 18.)

By connecting the ends of the primary coil of this arrangement, with the holes in the brass slips, M N, of Clarke's magneto-electrical machine, powerful shocks, and strong electrolytic effects are obtained from the quantity inductor; the spring Q, must rub on the double break, which in this experiment, performs the same office as Bird's contact breaker; the coil, which, as we have seen, is, when revolving before the magnets, a powerful source of electricity, supplying the place of the voltaic couple.

Thermo-electricity.—We have hitherto been treating of, and showing the connection between electricity, as derived from *four* different sources. First:—From friction, under the head of common electricity.

Secondly:—From chemical action, under the head of galvanism. Thirdly:—From some peculiar power, possessed by certain animals, as the raia torpedo, and gymnotus. Fourthly:—From certain arrangements with magnets, under the head of magneto-electricity. But there is a *fifth* source of electricity remaining to be noticed:—viz., that developed by the influence of temperature, which was first observed and made known, by M. Seebeck, in communications to the academy of Berlin, in the years 1821 and 1822, and to which the labours of intelligent experimentalists, have drawn of late years, an increased attention in this country.

The original observation of M. Seebeck, was, that electric currents can be excited in all metallic bodies, by disturbing the equilibrium of temperature, the essential conditions being, that the extremities should be in opposite states as regards temperature; hence, his apparatus was remarkably simple; it consisted of two different metals, soldered together at their extremities, and formed into frames of either a circular or rectangular figure, electricity was excited by the application of heat, to the places at which the metals were united, and evinced by the disturbance of the magnetic needle, balanced on a point between the extremities.

The maximum effects are produced, when the extremities of the metals, are in the extreme states as regards temperature; and it is therefore advisable to abstract heat from one extremity, by surrounding it with ice, while the temperature of the other extremity, is elevated by the flame of a spirit lamp.

Experiments have shown, that the thermo-electric properties of metals have no connection with their galvanic relations, or their capacity for conducting heat or electricity; neither do they accord with their specific gravities, nor their atomic weights.

In forming a thermo-electric series, it is desirable to combine an extreme positive, with an extreme negative metal. The subjoined table, by Professor Cumming, which is extracted from Mr. Watkins's "Popular sketch of electro-magnetism," exhibits the series; every substance being plus to that which precedes it, and minus to that which follows it:—

THERMO-ELECTRIC SERIES.	VOLTA SERIES, BY ACIDS.	SERIES OF CONDUCTORS, Of electricity.	Of heat.
Galena.	Potassium.	Silver.	Silver.
Bismuth.	Barium.	Copper.	Gold.
Mercury.	Zinc.	Lead.	Tin.
Nickel.	Cadmium.	Gold.	Copper.
Platinum.	Tin.	Brass.	Platinum.
Palladium.	Iron.	Zinc.	Iron.
Cobalt.	Bismuth.	Tin.	Lead.
Manganese.	Antimony.	Platinum.	
Tin.	Lead.	Palladium.	
Lead.	Copper.	Iron.	
Brass.	Silver.		
Rhodium.	Palladium.		
Gold.	Tellurium.		
Copper.	Gold.		
Silver.	Charcoal.		
Zinc.	Platinum.		
Cadmium.	Iridium.		
Charcoal.	Rhodium.		
Plumbago.			
Iron.			
Arsenic.			
Antimony.			

On inspecting the foregoing table of the Thermo-electric series, it will be seen, that the most efficient metals for eliciting a thermo-current are bismuth and antimony, and it is accordingly of these two metals that thermo-electric batteries are usually constructed. A simple apparatus may be made by soldering alternately together three bars of bismuth with three of antimony, and supporting the hexagonal figure horizontally with a magnetic needle, suspended within it; upon elevating or depressing the temperature of either of the joined parts, a deflection of the needle is perceptible.

Many trials have been made to construct thermo-electric piles, that would operate like the admirable instrument, for which we are indebted to the genius of Volta. It appears that the labours of M. M. Nobili and Melloni were first crowned with the greatest success. These two philosophers have constructed in common, a thermo-electric pile, with which they have made some very interesting experiments on radiant heat. The pile which M. Melloni used, was composed of fifty small bars of bismuth and antimony, placed parallel, side by side, forming one prismatic bundle, thirty millimetres* long, and something less in diameter. The two terminal faces are blackened. The bars of bismuth which succeed alternately to those of the antimony, are soldered at their extremities to the latter metals, and separated from each other at every other part of their surfaces, by some insulating substance, (silk or paper.) The first and last bars have each a copper wire, which terminates in a peg of the same metal, passing through a piece of ivory, fixed in a ring.

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* A metre is 39.37 inches; a decimetre 3.9 inches; a centimetre 0.39 inches; and a millimetre 0.039 inches.

The space between this ring and the elements of the pile, is filled with some insulating substance. The loose extremities of the two wires, are connected with the ends of the wire of a multiplier, which indicates by the motion of its needle, when the temperature of the furthest face of the pile is above or below that of the other.—*Becquerel's Electricity.*

Thermo-piles are now constructed in London, by most of the philosophical instrument makers, by soldering together at the alternate edges, plates of antimony and bismuth, intervening squares of card-board, or thick paper, being placed between the metals, to prevent their touching one another, and the terminal metals being furnished with wires, for the convenience of connexion.

The first account we have of the production of a spark from a thermo-electric apparatus, appears in a communication from Professor Wheatstone to the London and Edinburgh Philosophical Magazine; vol. x. page 414. The following is the simple statement.

The Cav. Antinori, Director of the Museum at Florence, having heard that Professor Linari, of the university of Siena, had succeeded in obtaining the electric spark from the torpedo, by means of an electro-dynamic helix, and a temporary magnet, conceived that a spark might be obtained, by applying the same means to the thermo-electric pile. Appealing to experiment, his anticipations were fully realized. No account of the original investigations of Antinori, has yet reached this country, but Professor Linari, to whom he early communicated the results he had obtained, immediately repeated them, and published the following additional observations of his own, in L'Indicatore Sanese, No. 50, Dec. 13, 1836.

1. "With an apparatus consisting of temporary magnets, and electro-dynamic spirals, the wire of which was five hundred and five feet in length, he obtained a brilliant spark from a thermo-electric pile, of Nobili's construction; consisting only of twenty-five elements, which was also observed in open day-light.

2. "With a wire eight feet long, coiled into a simple helix, the spark constantly appeared in the dark, on breaking contact, at every interruption of the current; with a wire fifteen inches long, he saw it seldom, but distinctly; and with a double pile, even when the wire was only eight inches long. In all the above mentioned cases, the spark was observed only on breaking contact, however much the length of the wire was diminished.

3. "The pile consisting merely of these few elements, readily decomposed water, within such restricted limits of temperature, as those of ice and boiling water. Short wires were employed, having oxidable extremities; the hydrogen was sensibly evolved at one of the poles.

4. "A mixture of marine salt moistened with water, and of nitrate of silver, being placed between two horizontal plates of gold, communicating respectively with the wires of the pile, the latter after having acted on the mixture, gave evident signs of the appearance of revivified silver on the plate which was next the antimony.

5. "An unmagnetic needle placed within a close helix, formed by the wire of the circuit, became well magnetised by the current.

6. "Under the action of the same current the phenomenon of the palpitation of mercury was distinctly observed."

The principal results here stated, were verified by Professor Wheatstone; he employed a thermo-electric pile, consisting of thirty-three elements of bismuth and antimony, formed into a cylindrical bundle, three-fourths of an inch in diameter, and one inch and one-fifth in length: the poles of this pile were connected by means of two thick wires, with a *spiral of copper ribbon*, fifty feet in length and one inch and a half broad, the coils being well insulated by brown paper and silk. One face of the pile was heated by means of a red-hot iron, brought within a short distance of it; and the other face was kept cool by contact with ice. Two stout wires formed the communication between the poles of the pile and the spiral, and the contact was broken when required in a mercury cup, between one of the extremities of the spiral and one of these wires. Whenever contact was thus broken, a *small but distinct spark was seen*, which was visible even in day-light. Professors Daniell, Henry, and Bache, assisted in the experiments, and were all equally satisfied with the reality of the appearance.

At another trial Professor Wheatstone obtained the spark from the same spiral, connected with a small pile of fifty elements, on which occasion Dr. Faraday and Professor Johnston were present, and verified the fact. On connecting two such piles together, so that the similar poles of each were connected with the same wires, the same was seen brighter.

Some experiments on the chemical action of the thermo-electric pile, were made *anterior* to those above described, by Professor G. D. Botto, of the university of Turin, with a different arrangement of metals; his experiments are published in the Bibliotheque Universelle for September, 1832. His thermo-electric apparatus was a metallic wire or chain, consisting of twenty pieces of platinum wire, each one inch in length, and one-hundredth of an inch in diameter, alternating with the same number of pieces of soft iron wire, of the same dimensions. This wire was coiled as a helix round a wooden rule, eighteen inches long, in such a manner that the joints were placed alternately at each side of the rule, being removed from the wood at one side, to the distance of four lines. Employing a spirit lamp of the same length as the helix, and one of Nobili's galvanometers, a very energetic current was shown to exist; acidulated water was decomposed, and the decomposition was much more abundant, when copper instead of platinum poles were used; in this case hydrogen only was liberated. The current and decomposition were augmented when the joints were heated more highly. Better effects were obtained with a pile of bismuth and antimony, consisting of one hundred and forty elements, bound together into a parallelopiped, having for its base a square of two inches, three lines, and an inch in height.

For developing electricity of feeble intensity, it is always best to employ a flat copper ribbon coil. Mr. Watkins found that he could always show a larger spark with it, than with an elongated wire coil and large temporary magnet; and that the snapping noise accompanying the thermo-electric spark, was more discernible.

Mr. Watkins arranges one of the extremities of his pile of strong sheet copper, cut like a comb, and covered with soft solder, and when the moveable extremity of the flat coil is passed over the comb, and the thermo-electric pile in action, splendid sparks are seen every time the moving part of the coil breaks the circuit, by leaving a tooth of the comb. With a pile consisting of thirty pairs of bismuth and antimony, one inch and a half square, and one-eighth thick, with the radiation of red-hot iron at one extremity, and ice at the other, a soft iron electro-magnet under the inductive influence of the electricity thus generated, supported ninety-eight pounds weight. The same experimentalist states that he has thermo-electric piles in his possession, varying from fifteen to thirty pairs of metallic elements, which give brilliant sparks by simply pouring hot water on one end, while the other end is at the temperature of the atmosphere; and that sparks are exhibited by the same piles, when the temperature is reduced at one end by the aid of ice, while the other end is at the temperature of the surrounding air. In order to effect the decomposition of water, Mr. Watkins employs a massive thermo-battery, with pairs of bismuth and antimony, a small apparatus for the decomposition of water, of the ordinary description, *(Fig. 45,)* and an electro-dynamic heliacal apparatus. The primary coil of wire is ninety feet long, and when the thermo-electric current simply pervades this coil, he does not notice any disengagement of the gases; but as soon as the contrivance for making and breaking battery contact is put in action, then an evolution of the gases takes place, while at the same time powerful shocks are received from the secondary coil of wire one thousand five hundred feet long.

From the interesting discovery made by Faraday, of the high conducting power of certain fused salts, for voltaic electricity, Dr. Andrews was led to imagine, that thermo-currents may be excited, by bringing them into contact with metals, and he succeeded in verifying this conjecture, in the following manner:—

Having taken two similar wires of platina, (such as are used in experiments with the blowpipe), and connected them with the extremities of the copper wire of a delicate galvanometer, he fused a small globule of borax, in the flame of a spirit lamp, on the free extremity of one of the platina wires, and introducing the free extremity of the other wire into the flame, he brought the latter, raised to a higher temperature than the former, into contact with the fused globule; the needle of the instrument was instantly driven with great violence to the limit of the scale. The direction of the current was from the hotter platina wire through the fused salt, to the colder wire. A permanent electrical current in the same direction, was obtained, by simply fusing the globule between the two wires, and applying the flame of the lamp in such a manner, that, at the points of contact with the fused salt, the wires were at different temperatures.

Dr. Andrews also succeeded in obtaining chemical decompositions, by this peculiar thermo-current. A piece of bibulous paper, exposing on each side, a surface of one-fourth of a square inch, was moistened with a solution of the iodide of potassium, and laid on a *platina plate*, which was in metallic connection with one of the platina wires used in the previous experiments. The extremity of the other platina wire in contact with the globule, was applied to the surface of the bibulous paper, and the flame of the lamp was so directed, that the latter was the colder of the wires, between which the globule of borax, or carbonate of soda, was fused. The platina plate in this arrangement, therefore, constituted the *negative pole*, and the extremity of the wire applied to the bibulous paper, the *positive pole*.* Accordingly when the circuit was completed, an abundant deposition of iodine occurred beneath the platina wire. When a similar wire of platina was substituted for the plate on the negative side, the effect was either *none*, or scarcely perceptible.

Dr. Andrews next formed a compound arrangement, by placing a series of platina wires on supports, in the same horizontal line, and fusing between their adjacent extremities, small globules of borax. The globules and wires were exactly similar to those that are used in blow-pipe experiments. A spirit-lamp was applied to each globule, so as to heat unequally the wires in contact with it; and the corresponding extremity of each wire being preserved at the higher temperature, the current was transmitted in the same direction through the whole series. By connecting the extremities of four cells of this arrangement, with an apparatus for decomposing water, in which the opposite poles consisted of a thick platina wire, and a guarded platina point, (both being immersed in dilute sulphuric acid,) very minute bubbles of gas soon appeared at the guarded point, and slowly separating from it, ascended through the liquid. They were obtained in whichever direction the current was passed, but rather more abundantly when the point was negative, and the wire positive. With only two cells, similar bubbles formed in a visible manner on the guarded point, but in such exceedingly small quantity, that they did not separate from it. With an arrangement, containing twenty cells, a doubtful sensation was communicated to the tongue, when the poles were applied to it; but no spark was visible, although the current was passed through a helix of copper wire, surrounding a bar of iron, and the contact was broken with great rapidity, by means of a revolving apparatus. It is necessary to observe, however, that the lamps were unprotected, and that it was impossible to render the flames of such a number of spirit lamps, burning near each other, so steady, as to heat at the same moment, in the required manner, all the globules and wires. With an enlarged and more perfect apparatus, Dr. Andrews thinks a spark might be obtained.

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* Dr. Andrews found that by using a *platina plate*, exposing an extensive surface, as one pole of a voltaic pair, and a fine wire of the same metal as the other, he could effect the decomposition of water; when, by employing a pair of similar platina plates, or similar fine wires as poles, he could obtain no such result. After the evolution of gas has ceased, he finds that an additional quantity is procurable, either by increasing the surface of the broad pole, or by removing it, and heating it to redness, or by reversing the direction of the current. Dr. Andrews accounts for this, by supposing, that when the poles exposed on both sides equal surfaces, the *gases were dissolved in the nascent state, by the surrounding*

Hence it appears, that an electrical current is al-

liquid: but when the polar surfaces were unequal, the solution of the gas being greatly facilitated by the broader pole, the element of water separated there was dissolved, while the other element was disengaged in the gaseous state, at the wire, which served as the opposite pole. In order, therefore, to discover, in case of difficulty, whether an electrical current is capable of decomposing water, or other substances, it is necessary to employ poles, having very unequal surfaces; and this will be effected in the most perfect manner, by opposing a thick wire, or plate of platina, to one of Wollaston's guarded points.—(See page 66.)

ways produced, when a fused salt, capable of conducting electricity, is brought into contact with two metals, at different temperatures, and that powerful chemical affinities, can be overcome by this current, *quite independently of chemical action.* The direction of the current, is not influenced by the nature of the salt or metal, being always, from the hotter metal, through the fused salt to the colder; its intensity is inferior to that of the hydro-electric current, developed by platina and zinc plates, but greatly superior to that of the common thermo-electric currents, and is capable of decomposing, with great facility, water and other electrolytes. Dr. Andrews found also, that currents were produced *before* the salt becomes actually fused, but that their direction no longer follows the simple law, before enunciated, bnt varies in the most perplexing manner, being first from the hot metal to the cold, then with an addition of heat, from the cold to the hot; and again, with a second addition of heat, from the hot to the cold.—(See Dr. Andrew's paper, in the tenth volume, and 433 page, of the London and Edinburgh Philosophical Magazine.)

But I must now bring this lecture to a conclusion, and with it the present course. I have endeavoured, in these lectures, to give a popular and generally interesting account, of the now extensive science of electricity. If their perusal has the effect of enlisting a few more labourers in its service, my object will be accomplished, and no one will regret so doing, for it must not be thought, that it is the *profound* electrician alone, that is qualified to enrich the science,—no mistake could be greater; every intelligent experimentalist, is capable of communicating novel and interesting facts—the field is open to all. At the present time, peculiar advantages are laid open to the tyro. An electrical society has been recently established in London, and if the future may be prognosticated from the present, its success will be triumphant; rarely a month passes, without some new and important fact being announced, or some new apparatus exhibited; conversation is unrestricted; and here the beginner may, from the experience of the more advanced enquirer, get his difficulties removed, and so have fresh encouragement given to his own labours. One of the greatest impediments to the science of electricity, (and it is the same with every other experimental science), was the isolated manner in which it was pursued; and, many are the young enquirers, whose ardour has been damped, nay, who have rejected the study with disgust, from being baffled with phenomena they could not explain or understand, at their outset, and from not having a proper source from whence to derive information.

Many excellent works on electricity, are before the public, but the information derived from books, though it may do well for the closet, will generally be far from satisfactory in the laboratory; here more detailed instruction, particularly in manipulation, is required, and it is by actually witnessing the various operations performed, that the necessary information can be acquired; hence, the great advantages of a society, in which there is a community of taste and feeling, and in which knowledge is unrestrictedly communicated.

Lastly, when we reflect on the prospects, which are held out by the attentive study of electricity, of eventually giving us a clearer insight into the operations of nature, as connected with the animal, vegetable, and mineral kingdoms—when we consider the almost certainty of its usurping, at no very distant period, the place of steam, as a mechanical agent, and thus being made, in the most extensive manner, subservient to the uses, and under the control of man, little more inducement, will, I imagine, be wanting to increase the body of its cultivators, and to assign to it, its proper place, among the most important of the physical sciences.

THE END.

ERRATA.

Page 105, eighteen lines from the top of the page;—for "they will not give shocks, nor decompose water," read, "they will not give shocks *immediately*, and only decompose water *feebly*."

Page 144, four lines from the top of the page;—for "no shock can be obtained, nor the slightest electro-chemical effect exhibited," read, "no shock can be *immediately obtained*, and very feeble electro-chemical effect exhibited."

Page 148;—for "*ελεκτδον*," read, "*ελεκτρον*."

Page 159, last line in the page;—a full stop after "attacked," and dele stop after "currents," page 160; also same page, thirteen lines from the top, for the second "hydrogen," read, "oxygen."

Page 184, thirteen lines from the top;—for "is," read, "are."

Page 239, seven lines from the bottom;—for "net," read, "magnet."

Page 245, eight lines from the bottom;—dele full stop after "Theodolite."

Page 246, six lines from the top;—for "joint," read, "point."

Page 302, four lines from the bottom;—for "approved," read, "appeared."

Page 306, twelve lines from the top;—for "needle," read, "wire."

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